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DRAINAGE PROBLEMS

IN THE

GANGES DELTA.

A SERIES OF SIX LECTURES DELIVERED AT

THE SIBPUR ENGINEERING COLLEGE

DURING

MARCH 1913.

BY

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DRAINAGE PROBLEMS

IN THE

GANGES DELTA.

LECTURE No. I.

Introduction.—The subject, which has been selected for these lectures, is that of agricultural drainage in tidal tracts. A series of lectures were given at this College in 1904 by the late Mr. G. C. Maconchy, Superintending Engineer, on "Problems connected with Flood Drainage," in which the mathematics of the subject were fully propounded. I do not propose going over this ground again, but, instead, will show you how these principles are applied practically in the design of the works necessary for draining land in deltas of rivers; the title I have chosen for my lectures is therefore "Drainage Problems in the Ganges Delta." I shall for the most part confine my remarks to actual problems which have come under my own notice close to Calcutta, where the congestion of drainage has been very marked of late years, and where a great deal of work has been done recently in supplying sluices and drainage channels to cope with the evil; my object is to lay before you the practical side of the question, so that you will have no difficulty in designing similar works, if at any time you are called on to do so. I may say that the principles laid down are also to a very large extent applicable to the drainage of lands which lie beyond the influence of tidal action.

The formulæ used have been mostly taken from Mr. Maconchy's lectures, and if any of you desire to ascertain how they are arrived at, you will be able to obtain the full details by reference to them; it would be a waste of time for me to repeat them, my intention being to demonstrate to you the method of applying them practically to specific cases. I have found, however, that it will be advisable to repeat a portion of one of Mr. Maconchy's lectures relating to the sluice calculations of the Magra Hât Drainage Scheme, as my lectures would not be complete without them. I shall first enter rather fully into the case of the formation of the Ganges delta, and the important subject of reclamation in the tidal portion of this Delta; after which the practical design of drainage works will be discussed.

Formation of Deltas.—The first subject on which I wish to speak is that of the formation of deltas; most of you must be familiar with some portion of the country surrounding Calcutta. As you know, Calcutta is situated on the western boundary of the vast delta of the Ganges; I propose to describe to you the way in which this delta has been formed, as it lies so close to your doors. You are all familiar with the Hooghly, and you know that this river forms one of the mouths of the Ganges. Extending from the Hooghly on the west to the Brahmaputra or Megna on the east, and bounded on the north by the Ganges itself, and the sea on the south, lies a vast tract of low-lying country, much of it covered with dense scrub jungle, and a great deal of it cultivated with paddy and other crops, which forms the great Ganges Delta. If we take a trip over this country we shall find

an innumerable number of rivers or creeks, some of considerable width, like the Hooghly, and others so small that only the smallest boats can ply in them. If we enquire as we go along we shall be told that some of the rivers are fed by fresh water from the Ganges, while in others the water is salty or brackish and is brought up by the tides from the sea. In some places we shall find that a new river has recently opened out, whereas another close by has lately silted up and become obliterated.

In the southern portions of the Delta we shall come into the jungle tracts. Here at high tide we shall see the water spilling over the banks and submerging the land; at low tide this ground will again become dry, the water finding its way back to the main rivers through innumerable small channels, locally called "*khals*."

In some places we shall see luxuriant crops being grown, while in others we shall hear many complaints of how the neighbouring channels have become silted, so that the drainage is choked and crops cannot be grown on account of the land becoming water-logged.

In a journey like the above we are brought into close contact with the forces of nature. In the northern districts will be found the oldest portions of the Delta, and in the southern parts the newest, or those which are still being formed. As the subject of the formation of deltas has an important bearing on schemes for draining the land so formed, I will as briefly as possible describe the process.

Delta formation by flood action.—A river in flood time carries an immense quantity of solid matter in suspension. In the case of the lower reaches of the Ganges this is composed of sand and fine mud. This material is deposited at the mouth of the river on the sea bed, which after many years becomes considerably raised; a time will eventually come when the ocean bed is raised so high near the mouth of the river, that the water will become shallow, and gradually shoals and islands will appear through which the river will force its way; in doing so it will follow the easiest route to the sea, and may at one time choose one particular channel and at another time another; or it may find its way through several channels. The result is that the silt and sand will now be deposited further out to sea and a new piece of ocean bed will be raised; as the new land so formed extends further out to sea, the length of the river will be increased; as the river mouths get longer and longer the longitudinal slope will be altered and become flatter; flood level at the head of the Delta will gradually rise, and the river will spill over its recently formed banks, raising them still further with deposits of sand and silt, and the land at the head will gradually become raised above tide level; in some cases the newly formed land may be raised above water level by the general upheaval of the ocean bed; but where this does not take place, the land is raised by a new set of conditions which I will now describe.

Delta formation by tidal action.—Let us consider what effect the action of the tides has on the newly forming land; as you know, the tides flow and ebb nearly twice a day (the average period being between 12 and 13 hours per tide). The tidal wave created by the attraction of the sun and moon conjointly approaches the mouth of the river: the water passing over the shoals picks up the newly deposited silt where the current is strong, and deposits it again in places where the current is slack; tide after tide does the same thing with the result that the ocean bed is raised, sometimes very rapidly, in patches. These patches continue to grow and eventually appear above the water surface at low tide, forming islands: as the tide flows in the islands are submerged and a fresh deposit of silt occurs; so that eventually a series of low-lying islands are formed at the mouth of the river, which are submerged at high tide. The river itself will find its way to the sea between these islands, forming a series of mouths; as time goes on the same process will be continued further out to sea, the river increasing the number of its mouths; later on further changes will take place and some of the mouths first formed will become joined into one, and the river will either find another new outlet or will deepen one of its existing channels. In the Delta of the Ganges such changes are frequent, as a comparison of the oldest maps with those of the present day will show.

An example of a large river which has totally silted up is that of the Ganga Nadi, which used to flow from the Hooghly at Hastings along the present Tolly's Nullah to Garia, and then turning south passed close to Barui-pore and Surjeepore and on to the sea somewhere near Saugor Island. The bed of this old river, which was the original course of the Hooghly, has silted up and become nothing more than an inland depression.

A case of a river which is at present following the same process is that of the Bidyadhari, which flows through the Salt Lakes to Port Canning where it joins the Matla. I shall have more to say about this later on.

Other cases are the Saraswati in the Howrah district and the Bhojrub in the Jessore district.

As the land becomes raised by tidal action dense jungle springs up, and the time eventually arrives when it has become high enough for cultivation. An embankment is thrown up all round to exclude the tides, the jungle is cleared, and the land is ploughed up and sown with crops.

It will be seen that, when the formation of new land is brought about by tidal action only, and there is no upheaval of the ground surface, the level of the land cannot be raised above high tide level; as the process continues, the rate of raising will get slower and slower. The reason is this; when solid material, such as silt or sand, is picked up by moving water, the heavier particles are carried along the bed and the finer particles in suspension in the form of mud and the quantity carried will depend on the velocity of the stream; a river with a velocity of 5 feet a second will be able to pick up and transport much more solid matter than one with a velocity of 2 feet a second, and it likewise follows that, if the velocity is reduced from 5 feet to 2 feet a second the water will not be able to carry so much silt, and some of it will sink to the bottom. In other words, the water will keep on picking up or dropping silt according as to whether the current increases or decreases. In a still pool, there being no velocity, the whole of the silt held in suspension will gradually settle to the bottom, the heavier particles first and the lighter ones afterwards. If there is a mixture of sand and mud, the sand will drop first and the mud afterwards; so that where the process is continued time after time over the same area, on digging down into the soil we shall find alternate layers of sand and silt. This is exactly what you will find in the Ganges Delta. If the silt-laden water is allowed to spill over the banks of the river on to the land, the velocity will be checked and its silt will be deposited on the land. The quantity deposited each tide will depend on the depth of the water on the land; the greater the depth the larger the quantity, and *vice versa*. As the land is raised the depth of water will become less and less, and the quantity of silt deposited correspondingly less. Before the ocean bed has risen above the level of low tide the whole of the tide will pass over it and in slack water a large quantity of silt will be deposited; later on, when the land has been raised, the first portion of the tide will be confined to the river bed, but as the tide rises further a spill will take place and the depth of water spilling being less, the quantity of silt will also be less. We come then to a state of things when the land has been raised so high that only the top of the tide spills, and, as the top layers of water contain less silt than the lower ones, the amount of silt deposited becomes so small that it may take many hundreds of years to raise the land another foot; we eventually shall arrive at a period when only the highest tides spill, so that only a few tides in the year will be of use in raising the land.

Tides.—I now come to the next important point, and to understand this we must go into the subject of the tides; as I have already said, the tide flows and ebbs nearly twice in the 24 hours. If we observe what happens we shall find that the flow lasts from about 4 to $5\frac{1}{2}$ hours and the ebb from $7\frac{1}{2}$ to $8\frac{1}{2}$ hours. The period of each tide from low water to low water or high water to high water varies from 12 to 13 hours; at each full and new moon the tides will run high, whereas at half moon they will have a small range. The former are called the "spring" tides and the latter the "neaps." The highest spring tides occur either in August or September and the lowest neaps in February and March: Taking the tides at Diamond Harbour on the Hooghly, we have the following results from the tide tables of 1912 to prove the above.

During the highest spring tides of the year :—

DATE.	HIGH WATER.		LOW WATER.		PERIOD OF		Range of tide.
	Time.	Reading.	Time.	Reading.	Flow.	Ebb.	
AUGUST.	H. M.	Ft. In.	H. M.	Ft. In.	H. M.	H. M.	Ft. In.
14th morning ...	0 1	19 9	8 15	1 2	...	8 14	18 7
14th afternoon ...	0 16	21 3	8 34	0 6	4 1	8 18	20 9
15th morning ...	0 40	20 4	8 53	1 0	4 6	8 13	19 4

Here the flow tide lasts about one half the time of the ebb.

During neaps of August.

	H. M.	Ft. In.	H. M.	Ft. In.	H. M.	H. M.	Ft. In.
22nd morning ...	6 46	12 10	1 8	6 5	5 38	...	6 5
22nd afternoon ...	7 33	11 11	2 9	6 8	5 24	7 23	5 3
23rd morning ..	8 27	13 3	3 1	6 5	5 26	7 28	6 10

Here again the flow is about five-sevenths the period of the ebb.

February Springs.

	H. M.	Ft. In.	H. M.	Ft. In.	H. M.	H. M.	Ft. In.
4th afternoon ...	0 44	15 10	9 10	1 0	...	8 26	14 10
5th morning ...	1 0	17 7	9 21	0 1	3 50	8 21	17 6
5th afternoon ...	1 26	16 2	9 10	1 0	4 5	8 14	15 2

The flow tide again lasts about half the time of ebb.

In February—Neaps.

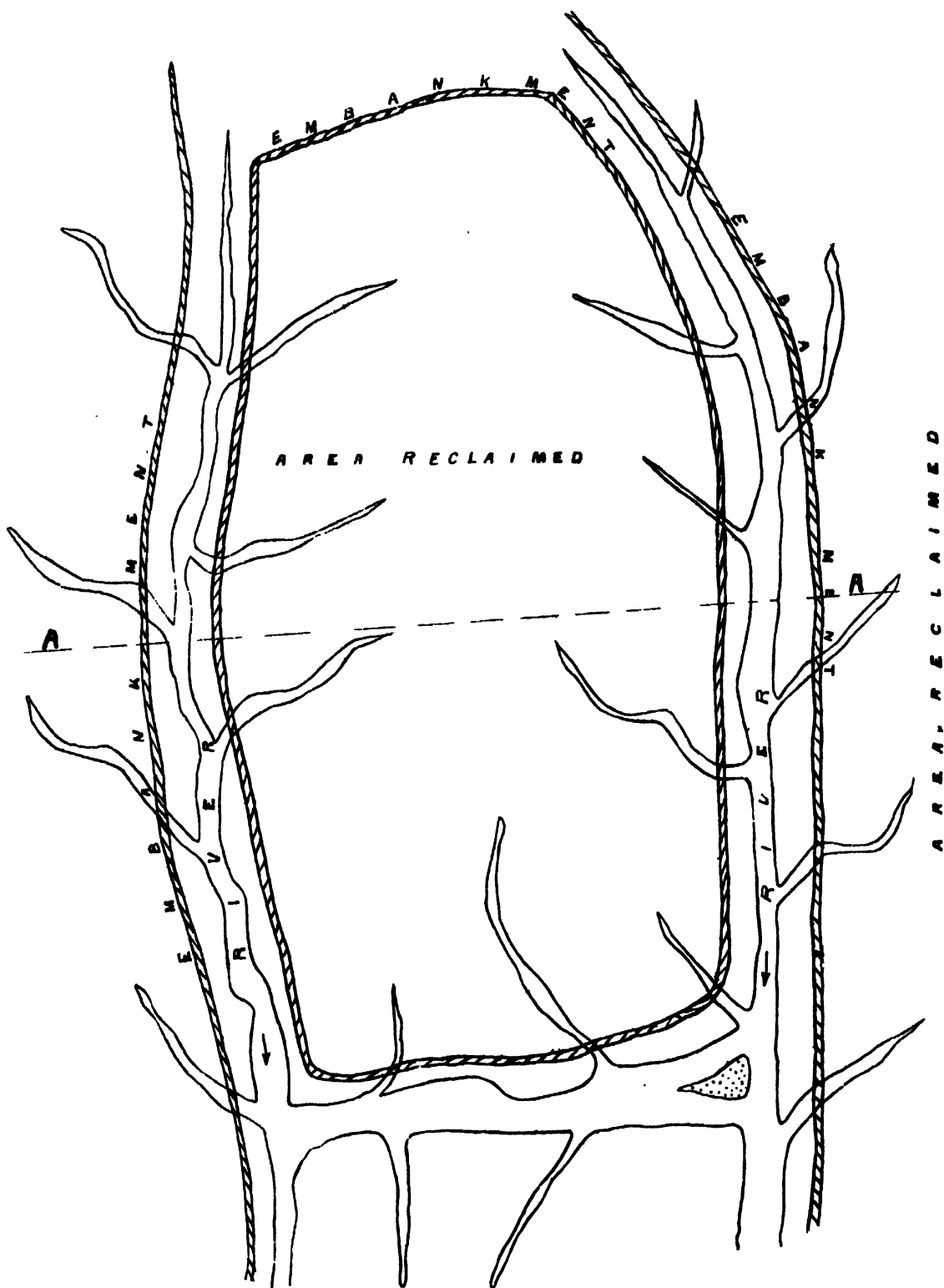
	H. M.	Ft. In.	H. M.	Ft. In.	H. M.	H. M.	Ft. In.
13th morning ...	8 28	8 10	3 2	4 11	5 26	...	3 11
13th afternoon ...	9 24	10 7	3 52	4 7	5 32	7 24	6 0
14th morning ...	10 0	9 5	4 59	4 2	5 1	7 35	5 3

Here the flow is about five-sevenths the ebb.

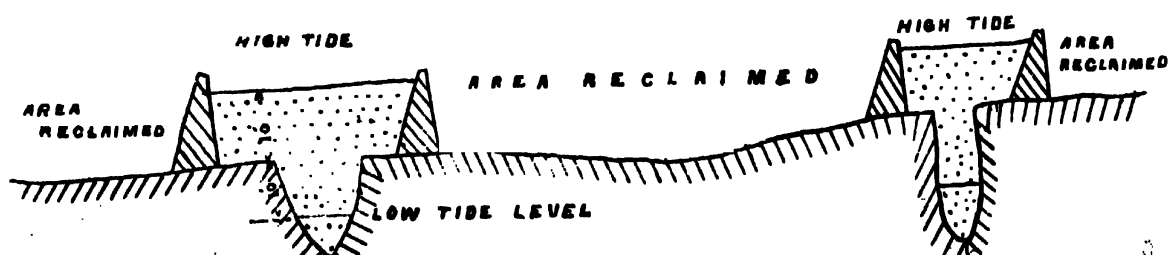
The points brought out by the above figures are most important, and I shall have occasion later on to refer to them again ; but for the present I wish to point out that the period of the ebb tide is always considerably longer than that of the flow. Roughly speaking, during spring tides the flow lasts about half as long as the ebb, and in neaps is about five-sevenths the ebb period. This circumstance is a most important one as the deterioration of tidal rivers is closely connected with it ; what does it mean ? It means this, that a river becomes filled with water during the flow tide much faster than it is emptied during ebb tide, and therefore the current generated by the tidal wave during flow is much stronger than that during the ebb. This

SKETCH PLAN SHOWING THE RESULTS OF PREMATURE RECLAMATION

FIG. I



SECTION ON A.A



again means that during flow the water picks up more silt than during the ebb. The tendency then is for some of the silt to be moved back from the bed of the sea to be deposited on the land on either side of the rivers and *khals*. Supposing now we prevent the tides from spilling, we shall confine the muddy water to the river itself; at high tide the current changes direction from flow to ebb, and for a short period there will be slack water. The silt held in suspension will commence to drop to the bottom of the river, but the ebb current being less strong than the flow, the water will not be able to pick up so much silt as was carried up by the flow, with the result that a portion of it remains behind lying on the bed of the river. The same thing will occur tide after tide, and eventually the river bed will become filled with silt, and the tides will practically cease to flow; at the same time the land which has been cut off from tidal spill will cease to rise, as the supply of silt has been cut off. This is what is going on now in many parts of the Sunderbans, and I need only quote the case of the Diamond Harbour Creek. The upper reaches of this creek in 1901 were in good condition and large country boats used it. In 1904 these reaches had entirely silted up and the bed was about 2 feet higher than the neighbouring fields. This was brought about by the tides being excluded from spilling into the low lands, by embankments constructed across the spill channels. In $2\frac{1}{2}$ years over 20 feet depth of silt was deposited in the upper reaches of this creek.

From what I have said it will be clear that as the land on the banks of a river is raised, the quantity of water spilling will become less and less, and consequently a less quantity will travel up the river. The current will be reduced and the river will adjust itself to the new conditions, and will silt up gradually as the quantity of water spilled decreases. While all these changes are going on we must not forget that the flood water from the main river forming the Delta has to get somehow or other down to the sea; what happens is that it will pick out certain channels through which the floods will pass while the other channels will disappear. It is these rivers which keep up the supply of silt which is necessary to carry on the formation of the new land. In the case of the Ganges Delta, the upper portion of the Delta has been raised somewhat by upland floods, with the result that the tides do not now extend up to the head and ground level at the offtake of the Bhagirathi is now about reduced level 65'00. The floods have cut out for themselves passages, one of which is the Hooghly. It may be asked why this river does not silt up like other rivers in the Delta. The answer is that, if it received no flood water at all, it would close up in a very short time; an immense quantity of upland drainage water passes Calcutta yearly during the rains, and further large supplies come in through the Rupnarain and Damooda rivers below Calcutta, so that the river obtains an annual flushing which keeps it open. If we were to close the offtakes from the Ganges, it would silt up in a few years. Some of the other rivers which carry fresh water from the Ganges to the sea are the Bhyrub, Jellingee, Gorai and Madhumati and the Megna.

Effects of reclamation.—You will see that once a tidal river is prevented from spilling, its life almost immediately comes to an end; now suppose that at any particular place, we choose a river and systematically cut off all means of spilling by erecting embankments on either bank; suppose the rise of the tide is 20 feet and that the land has only been raised say 10 feet above low tide level. Ten feet of the top of the tide is cut off from spilling, and the river at once commences to silt up; after a few years the bed will rise to the level of the land, and shortly afterwards will rise still higher, until the river bed becomes several feet above ground level (*see* Fig. 1). If in the meantime the land protected by the embankments is cultivated, we shall find that the drainage will become choked and there will be no outlet for the rain water. The average rainfall in the Sunderbans region amounts to over 60 inches in the year, and this water will lie on the surface of the ground to such a depth that, after the first few heavy falls of the monsoon, it will be so deep that the crops will be submerged and die, and the land becoming water logged will be thrown out of cultivation and remain a waste. It is then that the Drainage Engineer has to step in and improvise a system of drainage. The first thing he will find, when he inspects the country, is that

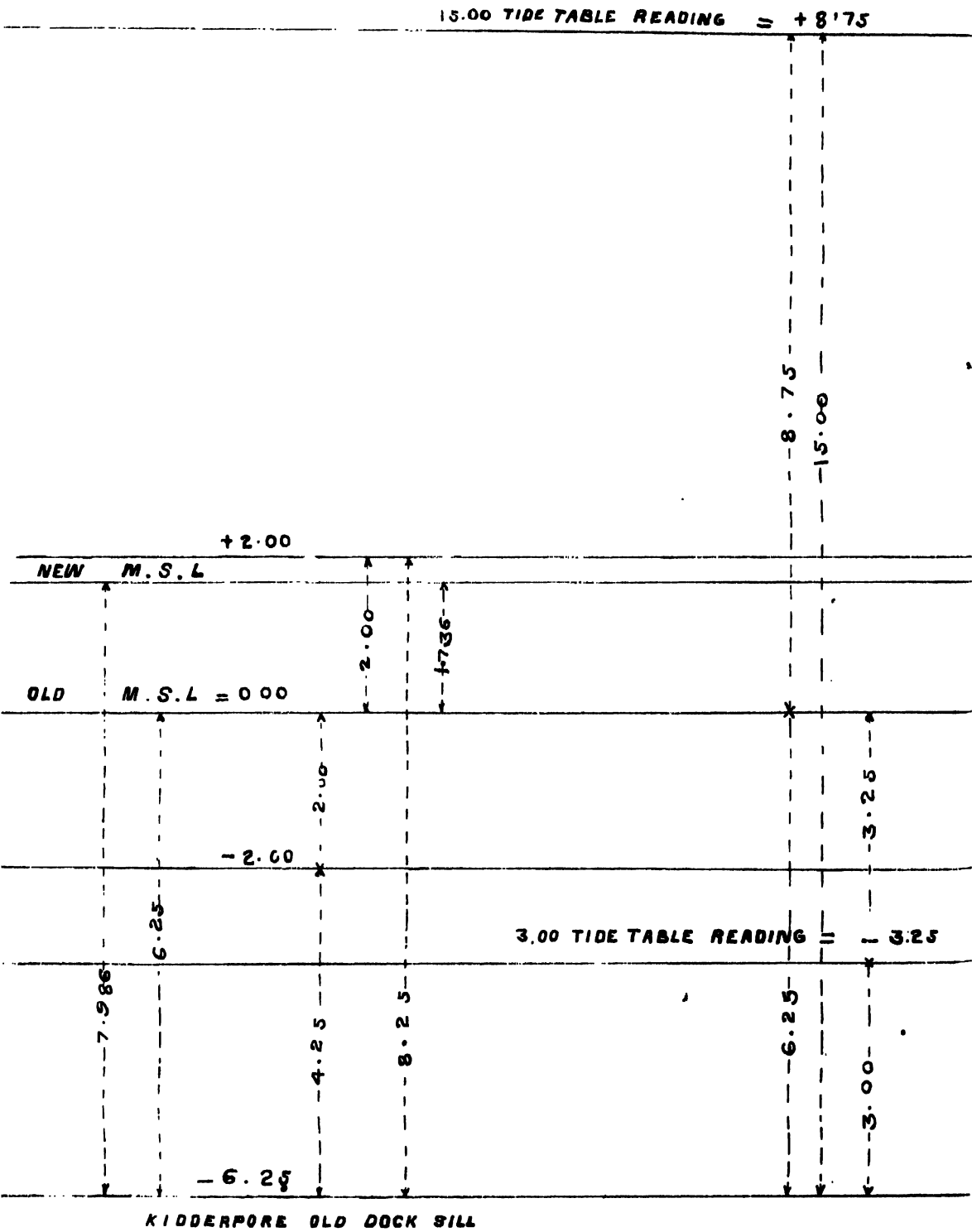
he has to find some new outlet for the water, or else to open up the old river again; and if the exclusion of the tidal spill has extended over a large area, he will have considerable difficulty in discovering a suitable river into which the water can be drained.

The further this river is away the more expensive will the works be, as the fall per mile will be less and the lengths and sizes of the channels will be increased. From a drainage point of view then it is clear that it is very important that the spill of the tide should not be interfered with until the land has been raised as high as possible by natural means. Government has recently fixed this level as being the mean of high water of springs and neaps. Let me give you an example of a case in which the bad effects of premature reclamation are very clearly shown. On the south-east of Calcutta are situated what are called the Salt Lakes. On the flow tide the water finds its way from the Bidyadhari river through side branch *khals* into the lakes and deposits its silt; on the ebb tide the water flows back into the river and the flow and ebb keep the river open. A part of the northern portion of the lakes called the Panchannagram basin was some years ago cut off from tidal spill by an embankment and brought under cultivation. In the meantime the tides have continued to spill into the lakes to the south of the embankment; the land has continued to rise in consequence, and is now about 6 feet above mean sea level, whereas that within the embankment remains at the original level when the embankment was made, or about 3 to 4 feet above mean sea level. We have therefore a low depression in the ground from which it is almost impossible to drain the rain water, and unless some means are devised by which a new outlet can be given, it is quite certain that these low lands will become entirely water-logged before long, and cultivation will cease. There are many such cases in the Ganges Delta; you will now see the connection between the formation of deltas and the drainage of the country, and how closely the one is allied to the other.

Conditions prevailing within the area enclosed by the 24-Parganas Embankment.—I want to impress upon you very strongly the ill-effects of premature reclamation, and I cannot better do so than by describing to you the conditions which prevail at the present day in the 24-Parganas district. The portion of this district which lies directly to the south and south-east of Calcutta will be described, as it is in this part of the country that the effects of premature reclamation are very marked and where in recent years a large amount of money has been spent in undoing the damage done. You will see before you an index plan of this part of the district (*see* Index map); I propose to describe to you the condition of the country, and why it is that so much money has had to be spent in draining it. The tract in question is enclosed within a circular embankment, which commences at Akra on the Hooghly and extends down the left bank to a place called Chitamari; the embankment then turns eastwards inland, and, after a series of windings, reaches the right bank of the Peali river along which it runs in a northerly direction to the Bidyadhari; it follows the right bank of this river to Samookpotta and then turns inland again in a westerly direction along the south bank of Tolly's Nullah and ends at Garia. It is marked patched on the map before you. The total length of this embankment is about 185 miles, and it encloses an area of about 735 square miles. Before this embankment was made the tides used to spill freely over the whole of this country, the level of which was gradually being raised. The land was covered with thick jungle, and was intersected by innumerable tidal creeks; as the tides spilled over the banks the velocity was checked, and heavy deposits of sand and silt accumulated on the banks and the lighter silt was carried more inland. The result is that the land was raised faster along the margins of the creeks, while at a distance the process was much slower: we shall find then that the land will have a slope inwards and downwards from the rivers. To give you an example of this, at Diamond Harbour, close to the left bank of the Hooghly, the reduced level of the ground is $10\frac{1}{2}$ feet above mean sea level, whereas only a few miles inland it is about 6 feet above mean sea level. If we take another case close to the same spot at Usti, which is 9 miles up the Diamond Harbour Creek (up till quite recently a tidal creek), we shall find ground level on the bank of the creek

DIAGRAM SHOWING THE RELATION
 BETWEEN OLD AND NEW M.S.L AND
 THE KIDDERPORE OLD DOCK SILL. ALSO THE
 MEANING OF " PLUS " AND MINUS
 LEVELS .

Fig. II



about 10 feet above mean sea level and about 3 miles inland it is about 5 feet above mean sea level. In some cases we shall find the level of the ground as low as 3 feet above mean sea level. The maximum height to which the tide rises at Diamond Harbour is 15 feet 3 inches above mean sea level, and it is therefore clear that the whole of the area enclosed within the embankment lies at a level which is several feet below high tide level; we even find now in a few cases that the embankment is cut through at certain places after heavy rain in order to drain water from outside on to the lower lands inside, the land outside having been exposed to tidal action for a longer period and having become raised higher than that inside. If therefore we were to remove the embankment the whole of the country would again be submerged with tidal water at high tide to a considerable depth. I have just given you certain levels of the ground above mean sea level. I will now tell you what is meant by mean sea level. It means the mean level of the sea throughout the year, and in this part of the country its value is fixed by referring it to a certain given fixed level, viz., the Kidderpore old Dock sill. It was found after observation that mean sea level was $6\frac{1}{4}$ feet above the level of this old Dock sill, but later on when further more careful observations had been taken, it was fixed at 7.986 feet above it; as the former value was used by the Public Works Department, up till the time the correction was made, it has been decided to adhere to it to prevent confusion. Let me impress upon you the importance of noting in your level books and reports and on your plans clearly to which mean sea level your levels are referred *always*: great confusion has arisen in several cases where this has not been done. The omission to do so may cause months of delay in an important project, whereas it only takes a minute or so to record this simple fact. All the levels I give you are therefore referred to the old mean sea level which is 6.25 feet above the Kidderpore old Dock sill. The value of mean sea level is 0.00, and any levels above this will be called "*plus*" levels, and any below "*minus*" levels: For instance, -2.00 means 2 feet below mean sea level and is $(6.25 - 2.00) = 4.25$ feet above the Kidderpore old Dock sill; +2.00 means 2 feet above mean sea level and is $(6.25 + 2.00) = 8.25$ feet above the Kidderpore old Dock sill. The Port authorities in Calcutta use the Kidderpore old Dock sill as their datum, as it is more convenient for their soundings and surveys, and the same datum is used in the tide tables. If we wish to convert the tide table readings into readings on our datum, we must subtract 6.25 feet from them. Thus a tide shown as being 15 feet 0 inches in the tide tables will be $\{(15' 0'') - (6' 3'')\} = 8' 9''$ when referred to mean sea level; similarly a tide of 3' 0'' will be $\{(3' 0'') - (6' 3'')\} = -3' 3''$ (see Fig. 11).

I have told you that the land slopes from the river banks downwards and inwards. It follows then that when rain falls the rain water will flow away from the rivers towards the lower lands, and if the *khal*s which drain these lands become choked with silt, as will occur as soon as the tidal spill is cut off, the rain water will go on accumulating, and the land will become water-logged and thrown out of cultivation; many such cases will be found in the area enclosed by the 24-Parganas embankment; up till quite a recent date the main drainage channels have been kept open by allowing the tides to spill into the low lands, the flow tide having a fairly free spill carried the silt held in suspension on to these lands, and the return ebb scoured back to the main river any silt which had deposited in the channel; gradually an attempt was made to reclaim the spill areas, and, as this proceeded, the rivers adjusted themselves to the new conditions, and some of them eventually became completely filled with silt and the beds rose above the level of the fields, so that the drainage was completely stopped and the water remained on the lands until it evaporated in the hot weather. If any of you have travelled from Calcutta to Diamond Harbour by train before the year 1909, you will no doubt, have observed vast areas of swamp lands submerged with water, as far as the eye could see, while the only signs of cultivation were on the higher lands round the village sites. This tract of country forms part of the low basin, which lies between the Hooghly and Peali rivers; the surplus rain water used to accumulate from all sides in this

basin, and the depth of water varied from 18 inches to 6 feet in the rains.

If we walk along the 24-Parganas Embankment we shall find many sluices of different sizes which have been built to drain the water from their respective basins, and to keep out the tides; it may be asked why the tides have been excluded: the answer is, that cultivation has progressed so far and the land has become so densely populated, that if the channels were opened out again and the tides allowed a free spill the whole country would be put out of cultivation and would have to be depopulated. The fact is the embankments were made too soon, before the tides had had sufficient time to raise the land. If the old *régime* were restored the cost would be enormous; and so it comes about that we have to choose the worst of two evils, and have to stop nature completing its work, and have to exclude the tides by making dams at the mouths of the tidal *khals* and building sluices through which the rain water can be discharged into the river which is closest and in the best condition. You will still find what are called "open *khals*," through which some of the basins are drained, but they will all have to be treated in the same way in the near future as they all show signs of closing up.

Up till quite recently the sluices which have been built have only touched the fringe of the area enclosed by the embankment. In the year 1905 or only 8 years ago, out of 735 square miles, it could be said that only 215 square miles were supplied with efficient drainage works; these works for the most part drained small basins close to the embankment, and the great central tract was left untouched. Since then a great deal of work has been done, more especially in connection with the Magra Hât Drainage Scheme, and at the present time about 520 square miles have been supplied with sluices and their connected works, and drainage schemes have been prepared for the major portion of the remaining area.

LECTURE No. II.

Method of preserving drainage channels by maintaining a spill.—I

would now like to say a few words on the subject of how the unsatisfactory conditions prevalent within the 24-Parganas Embankment can be prevented in other tracts open to tidal spill before passing on to the subject of the design of works. Further to the south and east, reclamation is in progress in many parts of the Sunderbans regions. If this is continued promiscuously, the same congestion of the drainage will occur as prevails within the embankment. In fact, trouble is already being experienced in some cases. To reclaim land the following works are carried out ; the jungle on the margins of the creeks is first cut down of a sufficient width to allow of an embankment being made all round the island. This embankment is then constructed, and any spill channels which fall in its way are closed with earthen *bundhs* so that the spill is cut off. The jungle is then all cut down and either burnt or carried off in boats and sold. The rain water is allowed to lie on the land during the rains, and in the cold weather small wooden box sluices are fixed in the embankment to drain it away. By this method the salt is gradually extracted from the surface, and in about three years' time, the land becomes sufficiently sweet to raise paddy crops. Now if the island reclaimed lies at or near the mouth of the river, the tides will continue to flow up and down past it and will spill over the unreclaimed portion above. This spill will keep the river open, and the land reclaimed can therefore be drained into it. The reaches of the river between the island reclaimed and the sea will to some extent deteriorate, but the spill above will prevent them becoming closed.

But if the reclaimed area lies at the head of the river, the spill being cut off, the head of the river will close up and difficulties will at once arise in disposing of the drainage. It is obvious then that if reclamation is allowed, the worst possible place to do it is at the head of the river, as it will affect the river all the way down to the sea ; and it therefore follows that in order to be able to drain the lands reclaimed it is most necessary to maintain a large spill area at the head of the river, as this will prolong its life, and in the meantime the land open to the spill will be gradually raised in level and will be more easily drained eventually. In some cases it will be advisable to regulate the spill, so as to make it occur at some particular point. The worst channels in the Sunderbans are generally those which flow from east to west, and they connect up those which flow north and south. The tide flowing up two of the latter rivers comes to the ends of the cross channel, and flows up it from both ends, meeting at some point or other ; where they meet the current is checked and there is slack water. The silt at once drops to the bottom and the channel becomes choked, and will eventually disappear ; if now we can create a spill on to the land at the point where the tides meet, we shall draw up the silt on to the land at this point, and maintain a strong flow and ebb in the channel both ways which will keep it open. This is an important point to remember, as it directly affects the question of the maintenance of the easterly running channels for the large steamer traffic between Calcutta and Eastern Bengal and Assam.

Examples of easterly running channels which have silted up or are doing so are the Angeria Creek, Coxali Khal, Atra Bunka and Tolly's Nulla.

I think I have now said enough to give you a good idea of the method by which deltas are formed and the ill-effects of premature reclamation in tidal areas ; but before proceeding to the practical side of this question I will sum up the chief points I have brought before you.

Deltas are formed by the action of rivers carrying solid material in suspension, which they deposit at their mouths due to a retardation in the velocity of the current.

The formation of deltas is assisted within tidal limits by the tides carrying back the silt inland from the shoals on the sea bed, so as to deposit it to form islands which are gradually raised by successive deposits of silt.

The slope of the land thus formed is downwards and inland from the rivers. Reclamation of new land should be postponed as long as possible until the land has been well raised. Premature reclamation does an immense amount of damage; it causes rivers to silt up and disappear, and chokes the drainage of the country and water-logs the land.

For preference spill areas should be maintained at the heads of tidal rivers.

The proportion of solid material carried by a river depends on the velocity of the current.

Preparation of drainage schemes: Preliminary Enquiry.—I will now take up the question of the preparation of drainage schemes and the design of works necessary in tidal tracts.

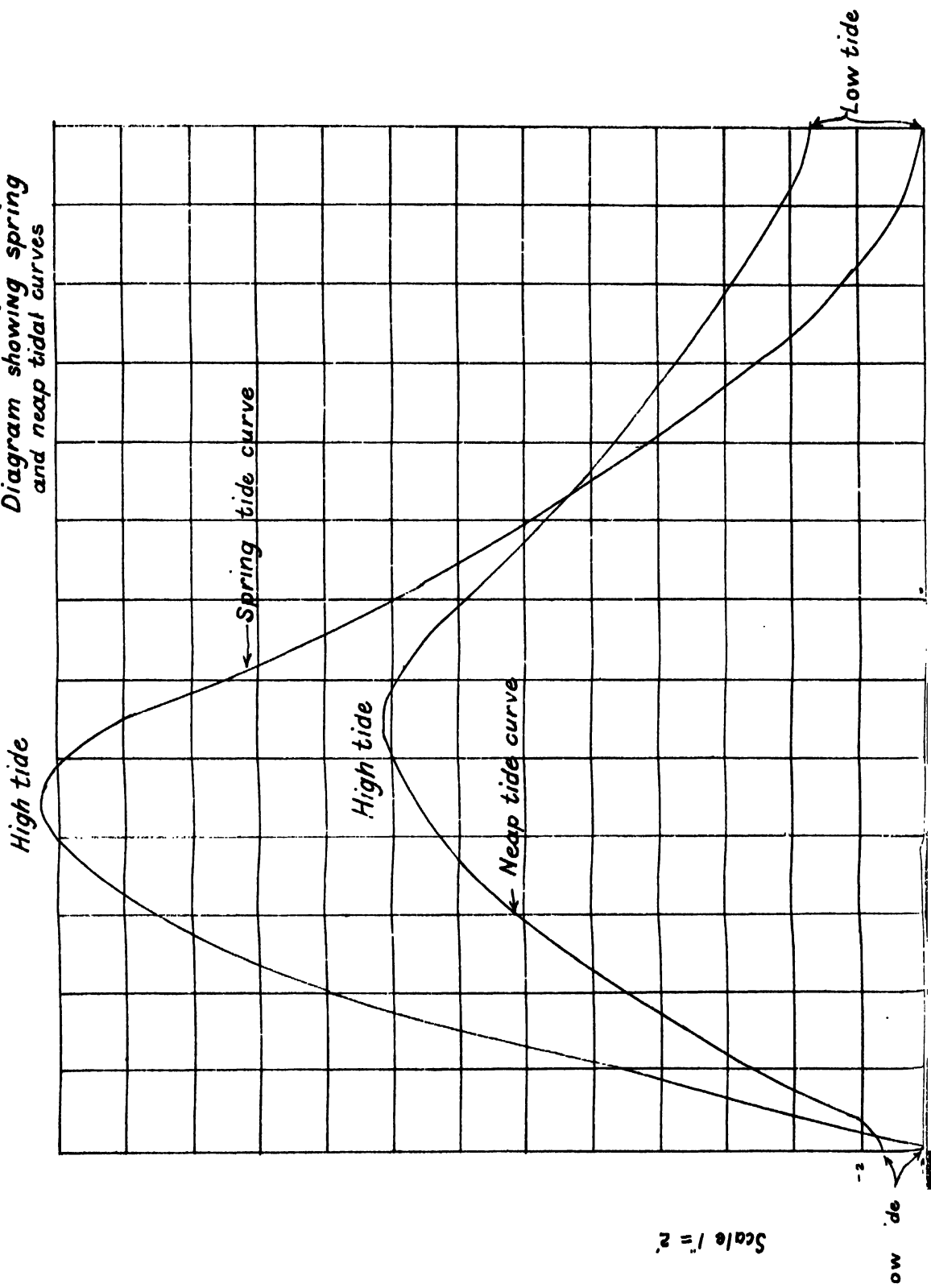
The works required are—a suitable channel through which to discharge the rain water. This channel must connect the low lands with the river. It must be closed at the mouth to exclude the tides, and a sluice must be built through which the water can be passed into the river. The channel must be bridged wherever necessary. The sluice cannot be built on the existing channel, as this has to be left open for drainage during construction, and the foundations will probably be very bad. It must therefore be built on new ground a little way from the channel and a connecting cut made to it called the diversion channel; when the sluice is completed the old channel is closed up with a cross dam and the water diverted through the new cut to the sluice.

Occasionally it happens that the low lands are close to the sluice, in which case no channel at all is necessary to lead the water to the sluice. A case in point is that of the Dhutkhali sluice. Sometimes the existing channel may be of sufficient section to carry the drainage, in which case the cost of works is decreased.

When it has been decided that a basin requires draining, the very first thing to do is to go personally and inspect the country in question. The best time for this inspection is during the rains when the land is submerged; you may obtain a perfectly different idea of the conditions prevailing by inspecting at this time of the year than if you inspected in the dry season, and you will also be able to take observations of the depths of water, etc., which you could not do at any other time of the year; on such inspections enquiries should be freely made of the local inhabitants as to why the drainage has become congested. A lot of useful information will be gained first hand; you will find old inhabitants most probably who remember the time when no trouble was experienced, and they will tell you how the water used to drain away. This information should be followed up and the old channels inspected and their condition noted; the rivers into which they lead should be inspected and any signs of deterioration in them noted. In fixing the river into which the water is to be discharged it is often of help to know how drainage is done at the time of inspection; you will probably find that some water is got rid of somehow or other, and by following this up you may find a better outlet than you obtained by following the line of the old drainage channels. It is sometimes much better to strike out on a fresh line, than to adhere to the old one; in the course of your enquiries you will very likely find that some of the water is drained across the boundary of the basin into some other basin, thus increasing the flooding in the latter; you will at once note this, and in preparing your scheme will try to prevent this happening: one of the most important matters to be decided is the position of the outfall, that is, the place where you are going to discharge the water into the river. The great thing to make sure of is that the river you have chosen is not a rapidly dying one; if there are any old cross sections of it, you should obtain them and have fresh ones taken at the same places; by plotting these new sections on to the old you will be able to see at a glance what is going on; you will know the dates on which each set of sections were recorded, and from these you can roughly estimate the rate of deterioration; at the same time you should explore the river above to ascertain whether it has a good spill area to keep it open, and, if so, whether there is any likelihood of this being reclaimed in the near future; in fact you must apply practically what you have learnt concerning the formation of deltas, and the effect of reclamation on this particular river.

Fig. III.

Diagram showing spring
and neap tidal curves



You should also ascertain whether the river is subject to land floods, and, if so, find out how long these floods last, and whether they are too high to permit of draining into it; the best type of river to choose is undoubtedly one like the Hooghly, which obtains a good annual flushing and will therefore keep open, as far as can be seen, for many years.

You must also satisfy yourself that there is no immediate chance of the river altering its course and leaving the sluice high and dry; also that the river is not rapidly encroaching, so as to threaten to outflank the sluice.

The worst possible place to build a sluice is at the upper end of a tidal *khal*, for although the drainage water will tend to keep it open, silting will go on during the dry months, and the *khal* will gradually close up unless periodically cleared of the silt. There are several cases where such mistakes have been made in the 24-Pargannas, such as those of Arapanch Khari and Surjipore. I shall tell you something about these later on.

If you cannot obtain a river which is annually flushed, then the best deep tidal river available should be chosen; the tides passing up and down in front of the sluice will then maintain a good outfall for some years at least, so long as there is a good spill area above.

If you are satisfied that the river is fast closing up, you must try and find some better outfall.

Inside the basin itself you should enquire of the local people the depth of water generally lying on the fields during the rains, and also the highest flood marks; you should confirm these figures by inspection during the rains and eventually, when carrying out your surveys, you should record the reduced levels of these marks; the ordinary and highest flood levels are figures on which all the calculations are based, and it is therefore most important that they should be accurately obtained.

You will probably find that most, if not all, of the old drainage *khangs* are silted up above the level of the fields, and you must bear in mind that it may be found cheaper to cut an entirely new channel across the fields than to excavate the old ones; and therefore, while gradually forming your ideas of the scheme you are going to prepare, you should keep your eyes open to find out the best alignments for such channels, avoiding as much as possible village sites. This saves in expense and also prevents disturbing the people; on the Magra Hât Scheme, which cost over 20 lakhs of rupees, we found it possible to carry out the scheme with practically no disturbance to the people in their houses, and only two small sheds had to be removed; you will in fact, as far as practicable, follow the lowest ground avoiding homestead lands, while at the same time taking the shortest route to the outfall.

The next thing to do is to have some fly levels taken over the country with a view to obtaining the level of the country generally and especially of the lowest lands. You must remember that you have to drain out the water perfectly dry for harvesting operations; your levels should be taken, as far as possible, along the lines chosen for the outfall channels, and you should have sections taken of any old drainage channels which exist. There may be several sets of low-lying lands in the same basin, and you must have levels taken between them, as you will have to connect them all up with small connecting channels. The positions of these low lands must be marked on the plan.

Tidal observations.—Then again when you have decided on the position of the outfall you should try to collect any information there is about the tides; in some cases this may have already been recorded, but in others you will have to fix a gauge at the site of the proposed outfall, appoint a trustworthy gauge reader, and record the high and low water levels of the tide; in addition to this the gauge reader should be made to take half-hourly readings of the gauge to enable you to plot out the tidal curves. The readings should be recorded from June to December, *i.e.*, throughout the drainage season; to plot a tidal curve the times at which the readings are recorded are plotted to a suitable scale horizontally and the gauge readings vertically, and you obtain a curve like the ones before you (Fig. III). The higher of the two curves represents a "spring" tide and the lower a "neap" tide; you will see that the spring tide curve rises very rapidly at first till about half flow tide, and then changes and rises slower and slower

until high tide is reached ; it then commences to fall, rapidly at first, and then much more slowly ; in the case of the neap tide the curve is much flatter, but of the same type as that for spring tides.

It is most important to have these gauge readings taken, unless you have records at some other gauge close by ; the variation will then be very small ; but the tides in different rivers vary ; for instance, maximum spring tide at Diamond Harbour rises to 15 feet 3 inches above our datum, whereas in the Peali river the level is only 12 feet.

In some cases the tidal curves are obtained by means of a self-recording tidal gauge operated by a float. The curves in front of you have been recorded in this way by the instrument at Kidderpore. This consists of a long drum which is revolved by suitable clockwork once in 24 hours. The paper on which the record is to be taken is wrapped round this drum, and the pencil which draws the curves is attached to the float. As the tide rises and falls the pencil is drawn along the paper one way or the other and records the height of the tide. The float operates suitable gearing, which enables the scale being fixed at any value required. In these particular curves the scale is $\frac{1}{8}$ th full size.

The highest spring tide level is of importance in fixing the height to which the sluice and other works should be built, to prevent overtopping, and on the low tide level will depend the level at which the floor of the sluice is placed as I shall point out later on.

In addition to the above information, a skeleton map of the basin to be drained should be prepared, showing the positions of the swamps, and the old drainage channels ; if this map is to a sufficiently large scale, the reduced levels of the ground can be noted on it, ground levels being shown in red ink and water levels in blue.

It is most important that the information collected should be as complete as possible ; a great deal of delay may occur due to some omission, and if the data on which the scheme is based are complete, they may lead to a total revision of the whole scheme, which may result in a more efficient and cheaper project being carried out. It must never be forgotten that you are dealing with the forces of nature, and if you make a mistake nature will find you out.

From the above you will now be able to make your rough estimate, which, with a few explanatory preliminary plans and a full report, have to be submitted to Government ; as the rough estimate is made out on the same principles as the detailed one, in order to avoid repetition I will not describe the way in which it is prepared.

Detailed calculations and estimates.—I will now describe how the detailed calculations and estimates are made ; and in doing so, I think the best plan will be to give you the details of a drainage scheme which has recently been executed. I have chosen the Magra Hât Drainage Scheme in the 24-Parganas, as this scheme is the last that has been carried out, and it is also the largest. As I have already told you, there lies a large area of low-lying country between the Hooghly and the Peali rivers which forms part of the large central basin enclosed within the 24-Parganas Embankment ; it is shown on the Index map before you.

Attention was drawn to this basin, which in all measures 294 square miles in 1900, after the heavy deluge which occurred in September of that year ; the rainfall recorded at Diamond Harbour and Surjipore, both of which lie inside the basin, was as follows :—

Date.	Surjipore.	Diamond Harbour.
18th	2.12	1.10
19th	9.80	3.95
20th	11.83	16.73
21st	5.70	7.85
22nd	0.90	3.58
23rd	0.76	0.45
24th	3.66	3.06
25th	0.50	2.05
Total in 8 days ...	35.27	38.77
Average per day ...	4.41	4.85

The fall of 16·73 inches in one day at Diamond Harbour is extraordinary and likewise the average daily fall from the 19th to the 21st, which amounted to 9·11 inches at Surjipore and 9·51 inches at Diamond Harbour.

The effect of the rain was remarkable; to quote Mr. G. C. Maconchy, who reported on this flood :—"The effect of the rain was remarkable even in a district which habitually undergoes severe flooding. Traffic on the Diamond Harbour Railway was interrupted, and the district roads were impassable except in boats; very large areas of crops were completely submerged; large numbers of houses fell and there was a considerable loss of cattle. The water subsided slowly; near Arapanch it had fallen only 1 foot 6 inches to 2 feet on the 4th October, and near the 12th mile of the Diamond Harbour Road it had fallen only about 1 foot 3 inches to 1 foot 6 inches on the 12th of October."

In fact the whole country was deeply submerged, the water finding its way from one basin to another, and parts of the country were not drained dry again for some months. An exhaustive enquiry was made into the causes of this extensive flooding. The whole of the area within the embankment was divided up into separate basins and a report prepared showing the requirements of each. The total area dealt with was taken as 719 square miles, and by a rough calculation it was shown that sluices requiring a ventage of 4,100 square feet, were required to drain this area, whereas the actual ventage existing was only 1,873 square feet; subsequent more detailed enquiries showed that the total area was 760 square miles and that a ventage of 4,322 square feet was required; an Index map was also prepared similar to the one before you, showing all the basins. Some alterations were made in the boundaries, and in some cases two or more basins were included into one drainage scheme. The final results are shown in the Index map. This map represents the conditions prevailing to-day. The basins which are supplied with efficient drainage facilities, those which are now being drained, and those which remain to be drained are indicated by different kinds of hatching. You will see that the whole area has been considered. This is an important matter; where possible, the whole of the area lying between two rivers in good condition should be considered. By doing this you then make certain that you have omitted nothing, and you will probably find that several basins can be combined into one project, which will cheapen the cost. Since 1900 a large amount of work has been done, and at present the total sluice ventage supplied is 3,308 square feet, and estimates have been prepared for another 760 square feet, which leaves only a few small basins to be dealt with. One of the proposals put forward was to drain the large central Magra Hât basin. Enquiries showed that many of the channels were silted up, and the only outlets were through the Diamond Harbour Creek on the west and the Surjipore sluice on the east. The creek ran almost into the central part of the basin, and up to Usti, 9 miles inland, was in fair order; beyond this up to Magra Hât, *i.e.*, the Nazra and Sangrampore *khal*s, it was badly silted and showed signs of closing up altogether; on the other side the Surjipore sluice (a 6-vented one) drained through the Surjipore *khal*, which was 6 miles long, into the Peali river; the *khal* was badly silted and the sluice was unable to discharge to its full capacity.

LECTURE No. III.

Magra Hât Drainage Scheme.

First scheme proposed.—The first scheme proposed was to build a new sluice at Usti to drain into the creek, a drainage channel being cut from the sluice to the swamps; this sluice was to serve the area north of the railway; a second sluice was proposed at the mouth of the Sangrampore *khal* to drain the country to the south of the railway. In order to preserve the creek from further deterioration, it was proposed to excavate the *khal* to Hatugunge and also those beyond; the idea was to keep these *khangs* open, so that the tide would have a free run in front of the two proposed new sluices; but it was found before these proposals were matured that the deterioration of the creek had advanced so rapidly that the Sangrampore and Nazra *khangs* had totally disappeared. When I saw these *khangs* in April 1905 the beds were from 2 to 3 feet above the neighbouring fields, and all drainage was totally blocked in this direction.

Second scheme proposed.—The idea of placing the sluices on the bank of the creek had therefore to be abandoned, and it was decided that the main sluice should be constructed at the mouth of the creek at Diamond Harbour, and the creek closed with a dam to exclude the tides and so prevent them from doing any further damage. At the same time it was found that as the Habka and Surjipore basins were so closely connected with the Magra Hât basin, it was desirable to include the three in one scheme to prevent an overflow taking place from one to another; the area drained by the Surjipore sluice was part of that to be drained by that at Diamond Harbour, and so could not be separated; in the case of the Habka basin an overflow would have occurred across the boundary; this basin had only one small open *khal* through which to drain the water, which was rapidly closing up.

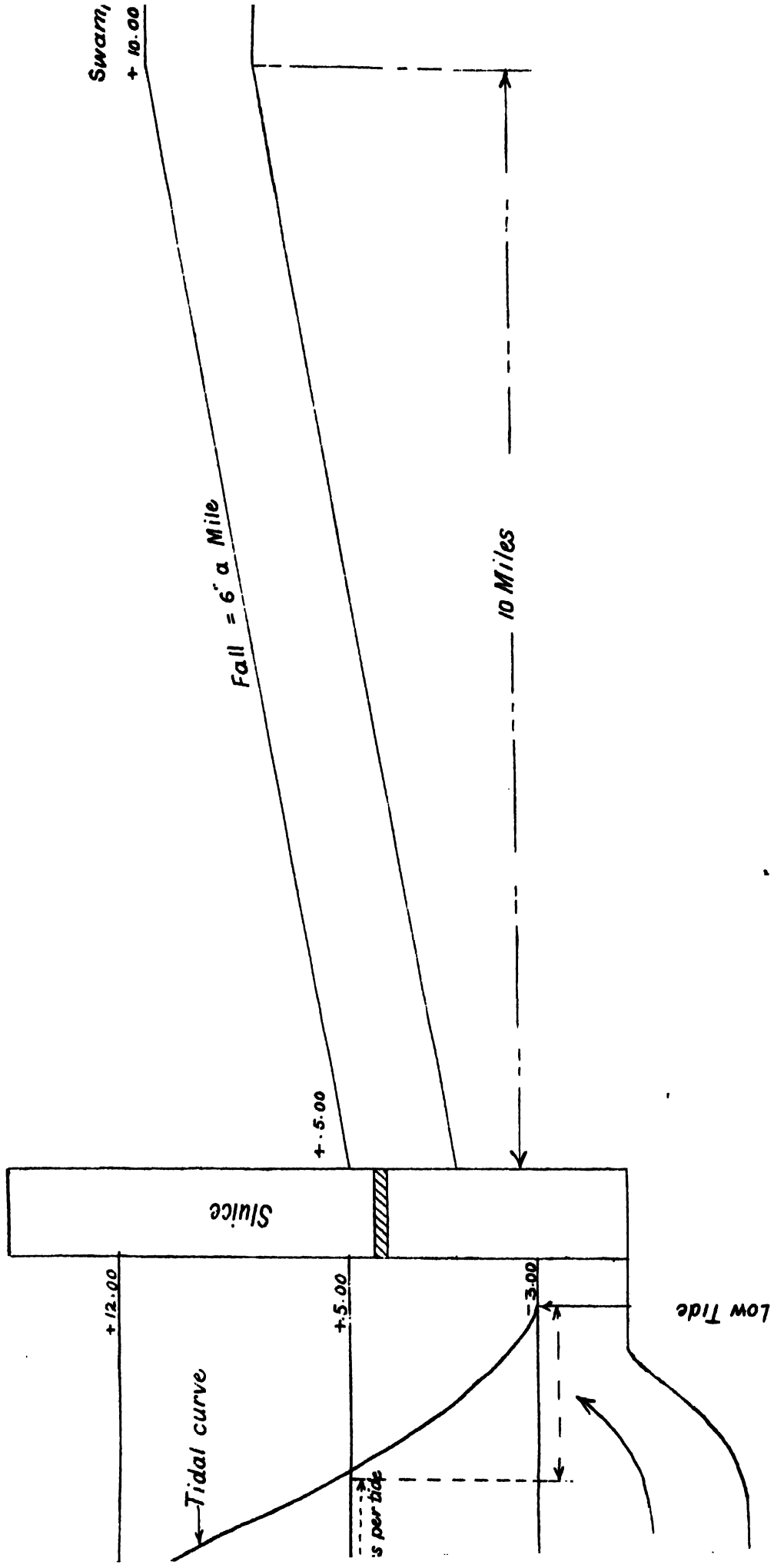
In the case of the Surjipore basin it was decided that the best thing to do was to excavate the Surjipore *khal*, and to place the sluice at the mouth on the bank of the Peali river, and to close the *khal* at the mouth to exclude the tides. The Habka basin was treated by building a sluice at the most convenient place on the Peali river, and the open *khal* was closed and a connecting cut made to the sluice. Thus it will be seen that the rivers chosen were the best available, both being large and deep. As already stated, it would have been a great mistake to have placed the Diamond Harbour main sluice at Usti, as before it could have been brought into operation the creek would have silted up and the sluice left high and dry; by advancing it to the margin of the best river available, the scheme has been made a most effective one. The above shows how important it is to examine the channel into which it is proposed to discharge the water, to prevent expensive works being rendered useless shortly after they are constructed.

The full black lines on the Index map show the channels which were excavated.

Choice of alignments for main outfall channels.—I now come to the calculations for the sluice and channels; surveys were made of the old channels, and water and ground levels recorded, the lengths of the channels being measured. From the surveys it was found that in the main Diamond Harbour basin the lowest land lay round Magra Hât; the lower reaches of the creek below Bindal were in good order, and between Bindal and Usti were silting up fast, but as yet the bed was lower than the fields; the creek was therefore chosen as the main outfall channel; the question then arose as to how the land to the south of the railway was to be drained; it was at first proposed to enlarge the railway bridge over the Kaorapukur *khal* near Magra Hât, in order to carry all the drainage to one channel on the north of the railway; the scheme was carried out under the Sanitary Drainage Act under which no compensation is paid for old river or *khal* beds; a railway bridge of 100 feet span existed over the Nazra *khal* and it was found that by using this and the Sangrampore *khal* the

Fig. IV

Diagram showing the period of discharge
of a tidal sluice



the cost would be less, as the land would cost almost nothing; so a main outfall channel was designed for the area north of the railway and another for that to the south. The total area of the basin is 215 square miles, of which 50 square miles lies to the south of the railway, and the railway bridge was found to be just wide enough to pass the water. In addition to these two channels which join at Usti, a third, called the Srichandra *khal*, enters the creek at the same place. This channel was fully silted up, but it was found to be the cheapest to re-excavate it, as the cost of land was small, the bed being wide enough for the spoil banks. The other channels will be mentioned later on, but the above three are the main ones.

Sluice calculations.—The total area drained by the sluice is, as stated, 215 square miles. In other similar schemes in the Howrah district it has been found sufficient if the works are made capable of lowering the flood over the whole area by $\frac{3}{4}$ inch in a day; to provide for such cataclysms as that of 1900 would be far too expensive; in normal years the above rate is sufficient, and is termed the "run off"; the rate of "run off" in this particular case was taken as '6 inch as a mistake was made in the calculations, but as will be seen later on the actual "run off" is more, due to reasons which will be mentioned.

Now if we were going to drain the basin into a non-tidal river, the discharge required would be:—

$$215 \text{ square miles} \times '6 \text{ of } 26.9 \text{ c. ft. second} = 3,470 \text{ c. ft. second.}$$

The figure 26.9 represents the discharge required to drain off 1 inch of water from 1 square mile per day, and is a figure to be remembered: it is generally taken as 27 c. ft. a second; but as we are draining into the Hooghly, which is tidal, the tide will rise above the level of the drainage water during high tide, and the sluice will cease to discharge for several hours a day, and an allowance has to be made for this. Let me explain what happens: at low tide the water will discharge freely through the sluice; as the tide rises the head will become less and less till finally, when the tide rises to the level of the water inside the sluice, discharge will cease. Supposing, for instance, the flood level in the swamps is 10.00 and the swamps are 10 miles away; if the longitudinal fall in the channel is 6 inches per mile, the level of the water at the sluice will be 5.00 (Fig. IV). If low tide level is - 3.00 and high tide is at 12.00, the sluice will continue discharging until the tide rises to the inner water level of 5.00; discharge will then cease while the tide rises to high tide at 12.00. It will still remain stopped until the tide has fallen to 5.00, when it will commence again; so that the sluice will operate as long as the tide is below 5.00 and will cease to do so as long as it is above 5.00; this is where the tidal curves come in; from these we can scale off the number of hours that the tide is below 5.00 and so obtain the period of discharge; suppose this is 16 hours per day counting the two tides, then we have to provide for an increased discharge ²⁴; this of

$$\text{of } 3,470 \text{ c. ft. second} = 5,205 \text{ c. ft. second.}$$

As a matter of fact, as the tide rises the discharge of the sluice will gradually get less as the head decreases, and the water coming from the swamps will collect or pond up in the inner channel, so that the sluice will cease to discharge at a somewhat higher level; this ponding up will continue while the tide is above the inner channel level, and the result will be that the sluice will commence to discharge at a higher level than that at which it ceased. In the case of a sluice discharging from a swamp which is close to it, both the closing and the opening levels may be the same as the water level in the swamp, but it can never be higher.

Breast-walls.—Now the tide level may fall as low as - 5.00 at Diamond Harbour in the drainage season; the main swamps are about 13 miles from the sluice, and flood level may rise to 12.00 in extraordinary cases; this means a fall of $12 + 5 = 17$ feet in 13 miles, or about 1 foot 4 inches per mile. The velocity due to this fall will be much greater than the soft alluvial banks of the channels can stand without erosion, and with water level so low at the sluice discharge will take place for only a few hours during the day. If we keep the low water level at the sluice as high as possible, we shall be able to drain for a longer time, and in some cases, during neap tides, when the range of the tide is small, discharge may occur over the whole tide and not

cease at all. A very simple way of keeping up the water level at the sluice is adopted : if we build a "breast-wall" or weir just above the sluice, the water level will not be able to fall below the level of the crest of this weir, and so long as the tide is below this level the discharge will not be affected ; as the tide rises above the crest it will start to back up the water, and decrease the discharge ; at the same time the water inside will pond up, but the tide, rising faster, will eventually come to the same level and discharge will cease ; of course, the raising of the level of the tail water at the sluice will decrease the longitudinal fall of the channels, and we have in consequence to design wider channels ; the cost of these will be increased, but the discharge of the sluice will be for a longer period, and we have to balance the one against the other to obtain the most economical results ; you will see before you a section of a sluice with a breast-wall to show what is meant (Fig. V).

If there was no breast-wall to the sluice, we should have to calculate the discharges from the ordinary sluice formula—

$$Q = CA\sqrt{2gh}$$

where "h" would be a varying quantity, depending on the rise and fall of the tides ; but as all tidal drainage sluices are now constructed with breast-walls the discharges must be calculated from the weir formula—

$$Q = 1\frac{1}{3} Lh\sqrt{h}$$

where L = the length of the breast-wall and h = the depth of water passing over it.

The length "L" is calculated from the discharge required, the head "h" being chosen from experience ; generally speaking, it is fixed between 3 and 4 feet : the reason is that with a greater depth of water falling over the breast-wall, the vibration set up may cause damage to the floor of the sluice where the water drops, as in this part of the country the foundations are not generally good enough to withstand too great a shock ; another and more important reason is that the less the value of "h" is, the greater the available fall in the channels will be ; in the Diamond Harbour sluice the depth of water was originally fixed at 3 feet, and the crest of the breast-wall at reduced level 0'00.

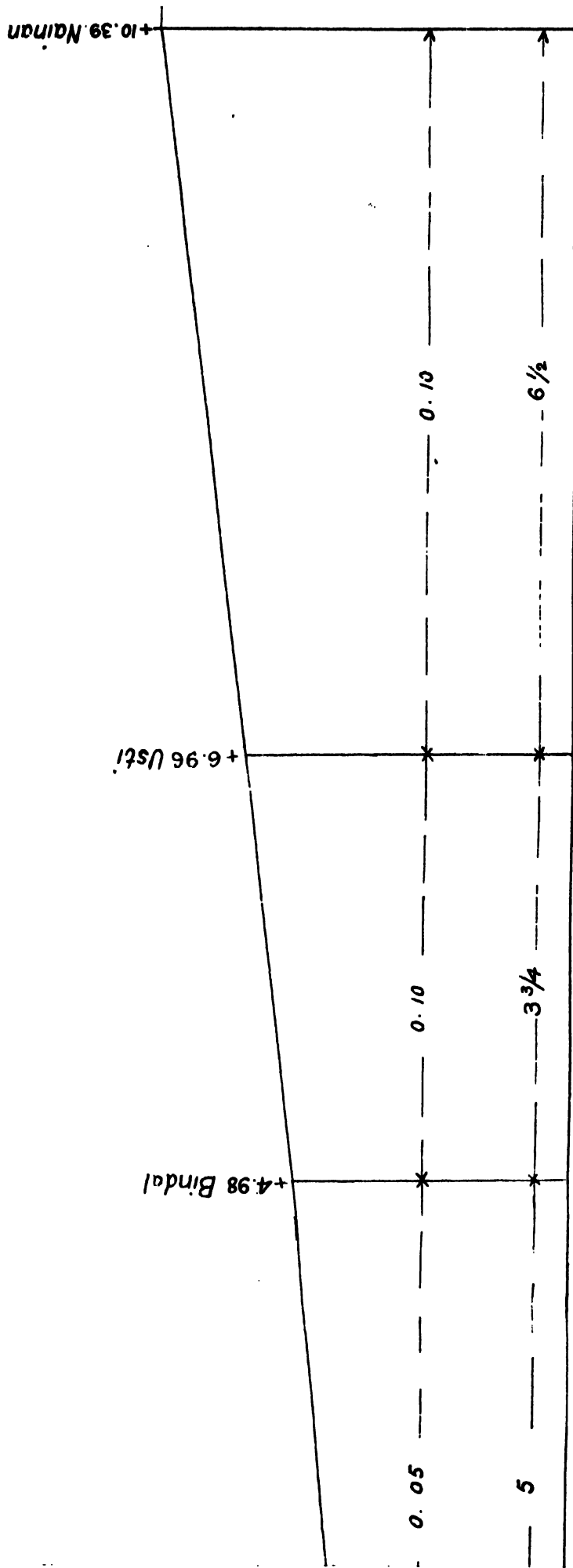
In the Usti sluice the depth allowed was 4 feet, and the crest of the breast-wall was + 2'00 ; in order to obtain as much fall as possible on account of the increased "lead" of 9 miles to Diamond Harbour, the depth over the breast-wall was decreased by 1 foot and the crest was lowered 2 feet, making a total gain of 3 feet.

During the large flood of 1900 it was found that the water rose to + 10'50 at Nainan ; ground level in the Kaorapukur basin is mostly between + 6'00 and + 7'00 ; it is a little higher towards Surjipore ; in the Sangram-pore basin it is between + 7'00 and + 8'00 ; the lowest is in the great Joynagar swamps to the south of Magra Hât, where it is about + 5'00 to + 6'00 ; with a flood level of + 10'50 almost the whole country is submerged, and, when drainage is commenced, the water will find its way across country and needs no channels except a main outfall.

I will first give you the original rough calculations and then describe how they were eventually modified.

The site chosen for the sluice was really the only one available ; it was chosen close to the Post Office, as the ground was open between this spot and the creek, so that only paddy fields had to be acquired for the new channel from the creek to the sluice (Fig. VI). At first this new cut was to have been $\frac{5}{8}$ ths of a mile long and a fall of 0'20 per 1,000, or 1 foot a mile was allowed in it ; water level at the sluice is fixed at + 3'00, and at the upper end of the channel near the creek becomes + 3'66 ; up to Bindal the creek was wide and deep and a fall of 0'05 per 1,000 or 3 inches a mile only was allowed, making water level at Bindal 5 miles up the creek + 4'98 ; from Bindal to Usti is $3\frac{3}{4}$ miles, and this was graded at 0'10 per 1,000, or 6 inches a mile, water level at Usti becoming + 6'96 ; from Usti to Nainan is $6\frac{1}{2}$ miles, and a fall of 0'10 per 1,000 was given, making water level at Nainan 10'39, or practically high flood level (Fig. VII).

Fig. VIII



Sketch Long Section of the Magra Hat
Main outfall channel as originally designed

APPENDIX VIII

Curve of Channel Discharges

Scale $\frac{1}{10}$

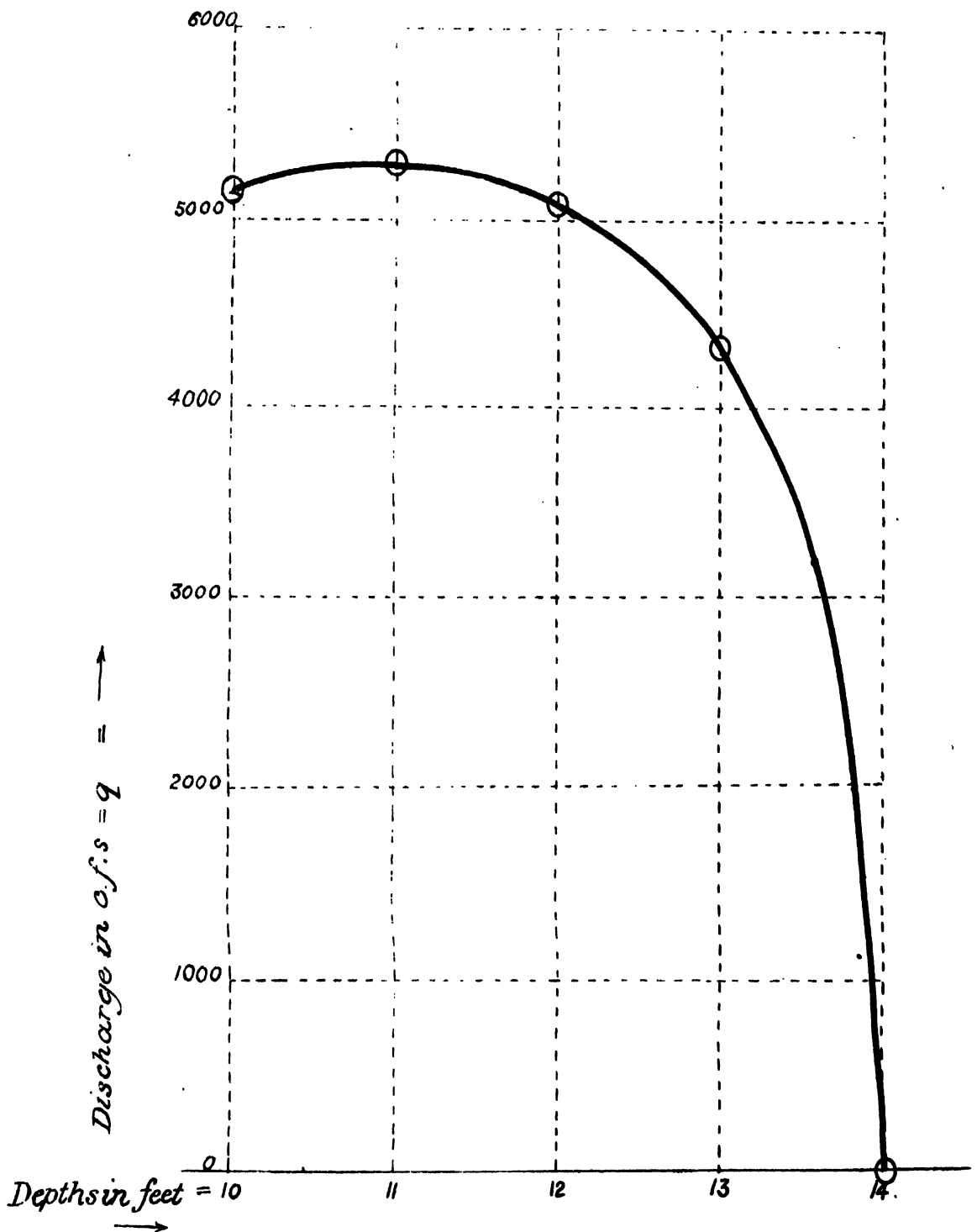
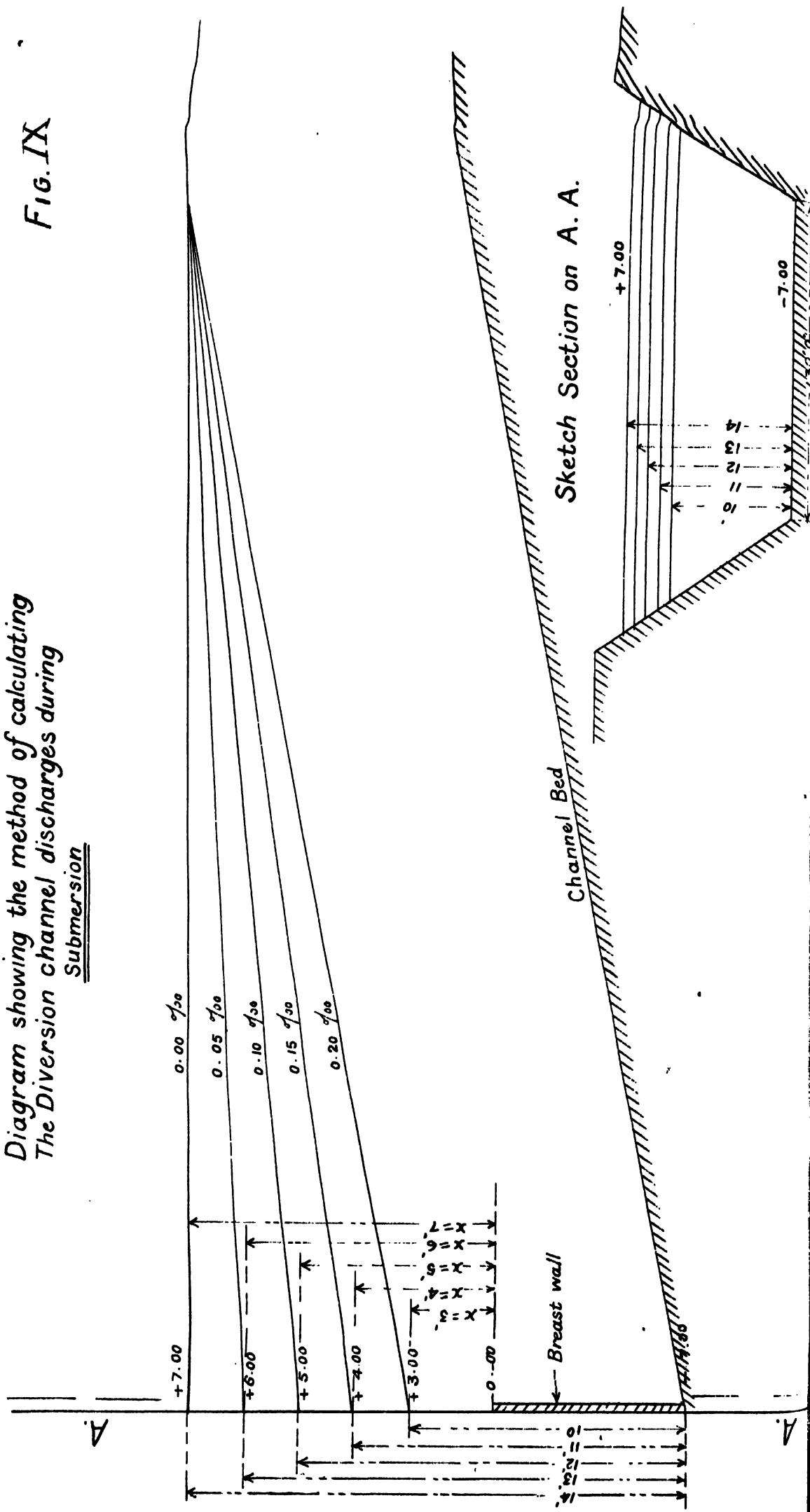


Diagram showing the method of calculating
The Diversion channel discharges during
Submersion

Fig. IX



Diamond Harbour Sluice average tidal curve
 showing periods of free and submerged
 discharges and closure.

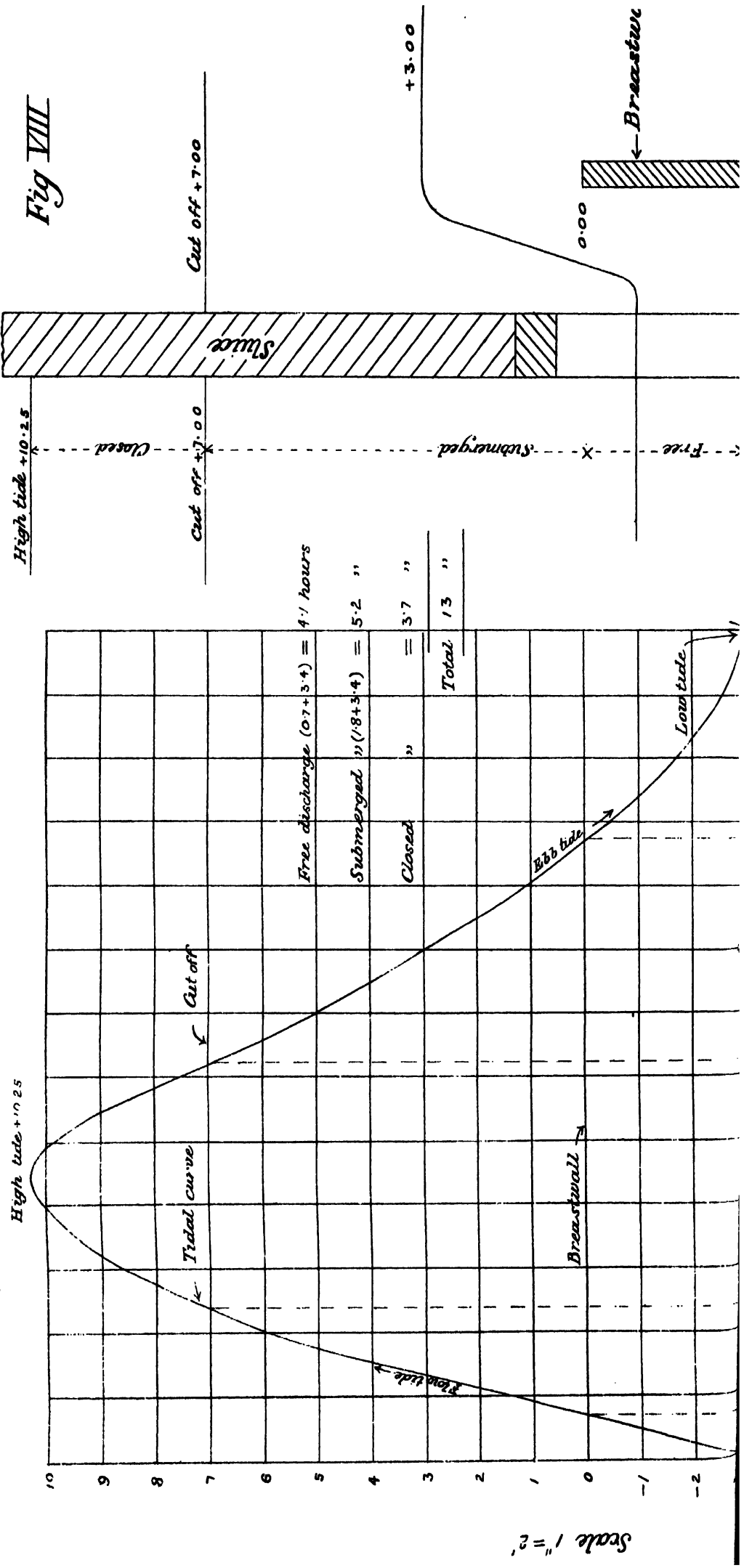


Fig VIII

Now it was assumed that when the tide rose, the inner water would pond up from + 3'00 to + 7'00 before the sluice closed, and to be on the safe side it was also assumed that discharge would commence at the same level. While the tide is below the crest of the breast-wall, which is reduced level 0'00, the discharge will be free, and as it rises from 0'00 to + 7'00 it will become "choked"; in the meantime the inner level will rise from + 3'00 to + 7'00; we have now to find from the tide curve the period that the tide level will be below 0'00 both for the flow and ebb tide; by scaling this from the tidal curve we obtain 4'1 hours; likewise the time that the discharge is "choked" is found by the same process to be 5'2 hours. As the tide lasts for 13 hours, the period of total closure is 3'7 hours (Fig. VIII).

We have now to ascertain the average discharge during submersion; to do this we have to find the different discharges of the outfall channel at different levels, that is, for different depths of water and longitudinal slopes; the bed-width has been taken as 130 feet and the depth of water 10 feet at low tide; with a longitudinal fall of 0'20 per 1,000 the discharge of the channel will be 5,138 c. ft. second, practically that required; I shall later on explain to you how discharges are calculated for the different channels; now flood level at Nainan is 10'50 and at the sluice + 3'00; the difference is 7½ feet fall; the length of the channel from the sluice to Nainan is 16 miles; the average fall per mile is then $\frac{7\frac{1}{2}}{16} = \cdot47$ feet; as the channel ponds up the longitudinal slope will decrease and eventually become "nil" at the sluice when the level of + 7'00 is reached; at the same time the depth of water in the channel will increase; we then have the following data from which the discharges are calculated: "x" in the table below is the depth of water passing over the breast-wall at any particular time; the depth of water in the channel near the sluice will increase from 10 to 14 feet and over the breast-wall from 3 to 7 feet (Fig. IX).

The level of + 7'00 will be 8'53 miles from the sluice. If you work out the slopes you will find they will be as shown in the table for different depths of water—

Depth	...	... = Ft.	10	11	12	13	14
x	...	... = Ft.	3	4	5	6	7
Slope in diversion							
channel per 1,000	...		0'20	0'15	0'10	0'05	0'00
Bed-width	...	= Ft.	130	130	130	130	130
Area = A	...	=	1,400	1,551	1,704	1,859	2,016
Wetted perimeter = P	=		158'28	161'11	163'94	166'76	169'59
Hydraulic	mean						
depth = R = $\frac{A}{P}$	...	=	8'8451	9'6270	10'3940	11'1480	11'8880
S	...	...	·20	·15	·10	·05	·00
N = ·025; C = (from Jackson's Table II)	...	=	·87262	·89322	0'92247	0'98266	...
Q = 100 CA√RS	...	=	5,138	5,264	5,068	4,313	0

where N = the co-efficient of rugosity, taken as 0'025 for channels in fair order. The curve of discharges is as shown in Fig. X.

LECTURE No. IV.

We have now obtained the discharges of the channel for different depths and slopes, and the discharges over the breast-wall must be equal to these; more water cannot be discharged by the breast-wall than is brought by the channel and *vice versa*; they must be the same in both cases.

We next have to ascertain at what times we shall obtain the above discharges, and we can then plot out a discharge curve and find the mean discharge during submersion.

The formula for a drowned weir is that given by Mr. G. C. Maconchy on page 11 of his printed lectures, formula No. 11, viz. :—

$$Q = FC\sqrt{2g} b x^{\frac{3}{2}}$$

where F is the unknown quantity.

$c\sqrt{2g} = 5$; and $b =$ the length of the weir (taken actually as 296·64 feet).

The values of F are calculated from the above formula; thus, taking the second case in the table above,—

$$Q = 5,264 \text{ c. ft. second.}$$

$$b = 296\cdot64 \text{ feet}$$

$$c\sqrt{2g} = 5$$

$$x = 4'$$

$$\text{Then } F = \frac{Q}{c\sqrt{2g} b x^{\frac{3}{2}}} = \frac{5264}{5 \times 296\cdot64 \times 8} = \cdot44611.$$

From the table for F, page 14 of the same lectures, we look up the value of $\frac{y}{x}$, y being the height to which the tide has risen above the crest of the breast-wall, since drowning began, and is proportional to the time, since the tidal curve at this point is for all practical purposes a straight line. From the table we find that for $F = \cdot44611$, $\frac{y}{x} = \cdot7620$, using proportional parts; whence $y = \cdot7620 \times 4 \text{ feet} = 3\cdot05$ since " x " = 4 feet.

That is to say, when the tide has risen 3·05 feet above the crest of the breast-wall the discharge is 5,264 c. ft. per second both in the diversion channel and over the breast-wall.

Similar calculations have to be made for other values of q and x and the results will be as follows :—

$x =$	3 ft.	4 ft.	5 ft.	6 ft.	7 ft.
$q =$	5,138	5,264	5,068	4,313	0·00
$F =$	·66667	·44611	·30733	·19896	0·00
$\frac{y}{x} =$	0·00	·7620	·8986	·9570	1·00
$y =$	0·00	3·05	4·49	5·74	7·00

You will notice that when $x = 3$ feet and the breast-wall is discharging freely, $F = \cdot66667$ or $\frac{2}{3}$ rds. If we place this value in the formula for the

discharge, viz., $Q = F c\sqrt{2g} b x^{\frac{3}{2}}$ we get $Q = 1\frac{1}{2} b x^{\frac{3}{2}}$ which is the ordinary formula for a freely discharging weir.

If we set off the values of " y " as abscissæ and those of " q " as ordinates, we shall obtain the discharge curve; this is the one before you (Fig. XI); the area of the curve is obtained by scaling the ordinates to obtain the mean

between each value of "q" and multiplying this by the value of "y"; the result is as follows :—

	$3.05 \times 5,245 = 15,997$
	$1.44 \times 5,210 = 7,502$
	$1.25 \times 4,730 = 5,912$
	$0.26 \times 4,160 = 1,082$
	$1.00 \times 2,850 = 2,850$
Total	$7.00 \times 4,753 = 33,313$

By dividing 33,313 by 7.00 we get the value of the mean ordinate q_m as 4,753 c. ft. per second, that is to say, the discharge of the sluice and channel will average 4,753 c. ft. per second during the time the discharge is submerged between tide levels 0.00 to + 7.00. The discharge when free was 5,138 c. ft. per second, and the discharge during submersion is equal to full discharge for $\frac{1}{3}$ of 5.2 hours = .927 of 5.2 = 4.82 hours.

The period of free discharge was found to be 4.1 hours, so that the total period of full discharge is $4.82 + 4.1 = 8.92$ hours per tide = $\frac{2}{3}$ of 8.92 = 15.7 hours per day, assuming that the two tides have a period of 13 hours each. As we have assumed that the water will not pond up in the inner channel during the time when the sluice is closed, we may call the above 16 hours; we must then provide for a discharge of 50 per cent. more than would be required if the river was a non-tidal one, and this is what we generally find to be the case in practice on the Hooghly sluices. The discharge required in the case of a non-tidal river and for a "run off" of $\frac{3}{4}$ th inch in 24 hours is—

$$215 \times \frac{3}{4} \text{ of } 26.9 = 4,337 \text{ c. ft. second.}$$

We must now therefore provide for $4,337 \times \frac{3}{2} = 6,506$ c. ft. second. As stated before, a mistake was found in the calculations, with the result that the discharge actually allowed for was only 5,115 c. ft. per second, which gives a run off of 0.6 inch in 24 hours, in place of 0.75 inch; but as I have said, it is seldom that the country is completely submerged as it was in 1900, and we have taken the worst case, whereas the calculations are usually based on an average flood level, when the higher lands are above water, or do not require drainage. Actually, since the sluice has been in operation, we have found by observation that with flood level at + 9.00, and all three sluices open, the "run off" was at the rate of 0.96 inch per day, which is really more than expected, the reason for which I will explain later.

Design of channels.—I will adhere to the original calculations and will turn to those for the channels; the first thing to do is to ascertain the area drained by each; for this purpose the whole basin was divided up into separate smaller basins, each of which had its own drainage channels leading to the main outfall, which was the creek. The areas of these basins were determined from local enquiry, and also from the levels of the ground. Having obtained the areas, the discharges for each basin were worked out, first for a continuous discharge and then allowing for the effect of the tides. The first is obtained from the formula :—

$$q = A \times r \times 26.9$$

where A = the area of the basin in square miles, r = the "run off" = $\frac{3}{4}$ th inch in 24 hours, and 26.9 = the discharge in c. ft. per second, required to drain off 1 inch in 24 hours from 1 square mile; we have assumed that the sluice ceases discharging when the tide is above + 7.00, and we also assume that below the point where water level is + 7.00 in the channels, the discharge will also cease, so that the discharge for these channels has to be increased by 50 per cent.; this is not really correct; what will happen is that, as the level at the sluice gradually rises, the channel level will also gradually rise and the slope become less and less, but the water will continue to flow down; while ponding is going on there will always be a current towards the sluice, until the channels are filled up to the level of the flood.

The point at which the water level will be + 7.00 is at Usti, $9\frac{1}{2}$ miles away from the sluice, as we have found by grading, that water level at this place is + 6.96; we have therefore to allow for full tidal action below Usti; in the Usti-Nainan and Nazra *khal* outfalls, partial tidal action was allowed for, as the water will be to some extent backed up and the current retarded.

Taking the creek, we find that at Bindal 14 square miles drain into it, and about a mile below Usti the Dassanni *khal* enters, draining 10 square miles; the discharge required for the Bindalbas in is $\frac{7}{16} \times 14 \times 0.6 \times 26.9 = 339$ c. ft. per second and for the Dassanni basin $\frac{7}{16} \times 10 \times 0.6 \times 26.9 = 241$ c. ft. per second. The Bindal basin is already supplied with a channel, and no new works are required. The Dassanni is drained by a *khal* which was silted up and had to be excavated. The discharges of the creek now become:—

From the sluice to Bindal ...	...	= 5,115 c. ft. per second.
From Bindal to Dassanni <i>khal</i> -		
5,115 - 339...	...	= 4,776 ditto.
From Dassanni <i>khal</i> to Usti—		
4,776 - 241...	...	= 4,535 ditto.

At Usti the Usti-Nainan, Nazra *khal* and Srichandra *khal* all enter. The areas of the basins are 113, 50 and 28 square miles, respectively, and in the former two an increase of about 20 and 10 per cent. was allowed in the discharge to allow for partial tidal action; in the Srichandra *khal* no increase was allowed as the level of the basin was comparatively high; the discharges were—

Usti-Nainan	2,688 c. ft. per second.
Nazra <i>khal</i>	1,190 ditto.
Srichandra <i>khal</i>	565 ditto.

The only other channel of any size is the Sangrampore *khal*, which is a continuation of the Nazra *khal*; it drains the same area, viz., 50 square miles. It was considered that this channel would not be affected by tidal action, and a continuous discharge was therefore allowed.

The discharge required is then—

$$50 \times \frac{3}{4} \times 26.9 = 1,008 \text{ c. ft. per second.}$$

A “run off” of $\frac{3}{4}$ th inch in 24 hours has to be taken in this case, as the mistake in the sluice calculations does not affect this channel.

I will now show you how the dimensions of the channels are arrived at: if I take two cases it will be sufficient, as they are all calculated in the same way. I will take that of the Diversion channel. The discharge to be provided for is 5,115 c. ft. per second and the longitudinal fall is 0.20 per 1,000. We can find the section required from Jackson's Canal and Culvert tables. As the channels will be maintained in good average order, we take Table X where $N = .025$, which is for canals in earth in average good order, with side slopes one to one; we have first to choose a suitable depth of water; this we have taken as 10 feet. From the tables we find the following results with the above data—

A channel with 120 feet bed-width gives	
a discharge of	4,746 c. ft. per second.
And one of 140 feet bed-width	5,533 ditto.
The mean is	$\frac{10279}{2} = 5,140 \text{ c. ft. per second.}$

which is very close to what is wanted.

A channel with $\frac{120}{2} + \frac{140}{2} = 130$ foot bed-width will therefore be suitable.

Then let us take the case of the Nazra *khal*: the discharge required is 1,190 c. ft. second, and the depth of water has again been taken as 10 feet; the longitudinal slope is 0.05 per 1,000. If we look up the tables we shall find the discharges for 10 feet depths of water have not been worked out, and

we must do so ourselves ; we find from the tables that for 9 feet depth the discharges are as follows :—

For 50 feet bed-width	882 c. ft. per second.
„ 60 „ „	1,056 ditto.

As the depth is 10 feet, we shall probably find the correct bed-width between these two. Let us try 55 feet bed-width.

Then the area of the waterway will be—

$$A = 65 \times 10 = 650 \text{ s. ft.}$$

The wetted perimeter is $P = 55 + 2 \times 14 = 83$ feet, and the hydraulic mean depth is—

$$R = \frac{A}{P} = \frac{650}{83} = 7.8134. \text{ ,}$$

Turning to Table II of Jackson's tables, we have the values of C given for corresponding values of R and S ; the longitudinal slope is 0.05 per 1,000, and using proportional parts C is found to be .9086. Then, using the formula I used in calculating the discharges of the Diversion channel when working out the sluice calculations, which is—

$$Q = 100 \cdot C \times A \sqrt{R S}$$

$$\text{where } S = \frac{1}{1000} = .001$$

$$\begin{aligned} \text{then } Q &= 100 \times .9086 \times 650 \sqrt{7.8134 \times .001} \\ &= 1,168 \text{ c. ft. per second.} \end{aligned}$$

The discharge required is 1,190 c. ft. per second and the above result is quite close enough. With the help of Jackson's tables you will be able now to work out the sizes of the remaining channels ; it is most important for an irrigation engineer to become acquainted with these tables, as they save an enormous amount of work.

We have found the sizes of the main drainage channels ; we know the longitudinal fall in each, and the water levels at head and tail, and from these we can find the bed levels by deducting the depth of water from the water level. Thus in the Diversion channel low water level at the sluice is + 3.00 ; the depth of water is 10 feet, so that the bed level is $(3 - 10) = - 7.00$.

At the head of this channel, water level is + 3.66, and the depth of water as before, and the bed level becomes $(3.66 - 10.00) = - 6.34$, and so on for the rest.

LECTURE No. V.

Alterations in the Sluice Plans.—We have now obtained the necessary bed levels of all the channels; the next thing to do is to work out the quantities of earthwork in each; you will know the ground levels from your surveys and sections, and can obtain the depths of cutting at different chainages from which the quantity of earth can be obtained for each channel. You have also to ascertain the width of land required for the channels and spoil banks; before going into this subject I will first describe to you the alterations which had to be made in the plans; the low tide level at Diamond Harbour was taken as being -5.00 in the rains; and in order to prevent an excessive velocity in the outer channel between the sluice and the river, the upstream floor of the sluice was placed at -7.50 . The thickness of the floor was made $4\frac{1}{2}$ feet, making foundation level -12.00 . Excavation was commenced, but at reduced level -10.00 it was found that the character of the soil changed from blue clay to a fine running sand full of water, and it was found impossible to excavate down to the required level, because as fast as the sand was removed it filled in again, and it became evident that very costly foundations would have to be put in if this level was to be adhered to.

I may say that it is always best to put down some borings at the site chosen for the sluice, as a quick sand underlies the clay all over the lower portions of the Delta, and, if the level of it is high, plans have to be altered.

Pooling.—It was therefore decided to raise the upper floor to -3.50 , *i.e.*, by 4 feet, and in order to prevent uneven settlement, the walls were provided with well foundations; at the same time the crest of the breast-wall was raised to $+1.50$. The low tide level during the rains was found to be -3.50 instead of -5.00 , and at the same level as the upper floor. In designing sluices of this type very great care has to be exercised in preventing what is termed "pooling" below. If the water issues from the vents with a high velocity, and there is a large fall between the sluice and the river, the channel bed will be scoured out deep; and this is especially so, when the soil is composed of fine sand. The proper way to prevent pooling is to build the sluice floor at a level which will give a small velocity in the outer channel, say, not higher than 2 feet a second. In the present case we have found that this is not possible, and so we have to provide other means for protecting the sluice from damage by the "pot-hole" cutting back and undermining it.

Limitation of the Velocity through the Sluice.—Let us look at the conditions we have to take into account: the crest of the breast-wall has been raised to $+1.50$, and, assuming the same depth of water over it as before, water level becomes $+4.50$; low tide level is -3.50 . We have then a fall from the breast-wall to the river of $(4.50 + 3.50) = 8$ feet in a length of about 1,000 feet. The discharge to be provided for is 5,115 c. ft. second, and, as the floor of the sluice was raised, an extra six vents were given to the sluice, making 30 in all. This was done in order to prevent the choking of the discharge of the breast-wall as much as possible. In the original calculations the number of vents required was calculated on the assumption that the area should be equal to the area of the waterway over the breast-wall. The latter was 300 feet \times 3 feet = 900 square feet; the vents are generally made 8 feet \times 5 feet = 40 square feet each; so that the number required is $\frac{900}{40} = 22\frac{1}{2}$ which was called 24.

This is a very rough-and-ready method and contains a fallacy. Supposing the tops of the vents are above water level in the inner channel at low tide, then they will run only partially full, and the velocity through them may become very high, and if the sluice floor is high, as in the present case, there is nothing to break this velocity on the downstream side, and pot-holing is certain to occur.

The proper way to make the calculation is to commence from the river itself and to calculate the level of the water at different points, working upstream, as I will now explain. Working back from the river we have

low tide at -3.50 ; allowing 6 inches fall in the outer channel, water level becomes -3.00 below the vents.

In the floor below the vents a drop of 6 inches is generally allowed for the swing shutters to work freely; this makes the level of this floor -4.00 , so that there would only be 1 foot depth of water passing over it at low tide which would mean a velocity of $20\frac{1}{2}$ feet a sec. There is nothing to break this on the downstream side; the result would be that a large hole would scour out in the channel below and the sluice would gradually fall piece by piece into it as it was undermined: several sluices have been washed out in this way, and in some others expensive works have had to be undertaken to prevent the same fate befalling them; this shows how very important it is to place the floor at as low a level as possible; the level is determined entirely by the velocity in the outer channel which must be kept within safe limits to prevent pot-holing taking place.

Protection by Curtain Walls.—If sufficient protection can be given in the shape of strong drop or curtain walls on the downstream side, an allowance may be made for some scour in the outer channel, and this has to be done in cases like the present, where the nature of the foundations prevented a lower level being attained.

To prevent damage being done, two precautions were taken: the first was to build deep curtain walls on the downstream side, composed of wells 8 feet square; two lines of these were sunk right across the sluice at the ends of the two lower floors; the depth of these wells allowed for some pot-holing to take place, which actually occurred directly the sluice was opened; but the wells were too deep to be undermined. The second precaution was to limit the velocity of the water over the floors; the lowest floor was built at reduced level -6.00 , and there was a rise of 2 feet between it and the one above; with low tide level at the sluice of -3.00 there is always a depth of 3 feet of water over the lowest floor; the width is 250 feet and the velocity becomes $\frac{5115}{250 \times 3} = 6.8$ feet a second, which is quite safe over masonry. In the channel itself, to reduce the velocity to 2 feet a second the depth of water will be $\frac{5115}{250 \times 2} = 10.23$ feet, say $10\frac{1}{4}$ feet, making bed level at $-(3.00 + 10.25) = -13.25$. The lower drop wall was made $11\frac{1}{2}$ feet deep, and there is $1\frac{1}{2}$ feet of masonry above it composing the floor; so that the bottom of the wall is $-(6.00 + 11\frac{1}{2} + 1\frac{1}{2}) = -19.00$, or 5.75 feet below the bottom of the scour. (Fig. V).

Protection by Cushion Walls.—Now with regard to the upper downstream floor—we found that the velocity over this was $20\frac{1}{2}$ feet per second, which is more than advisable even over masonry. To reduce this the only thing to do is to increase the depth of water on the floor; this is done by building a cushion wall at the downstream end of the floor. In the present case the height of this wall was made $2\frac{1}{2}$ feet; the length of it is 250 feet, and it will be found that the depth of water over the crest required to give a discharge of 5,115 cubic feet per second is 3.39 feet. Since—

$$Q = \frac{10}{3} \times 250 \times 3.39 \sqrt{3.39} = 5,200 \text{ cubic feet a second.}$$

Water level at the crest of the cushion wall then becomes $+1.89$; the depth of water in the vents will now become $(3.50 + 1.89) = 5.39$ feet, while over the floor below the velocity will be reduced from $20\frac{1}{2}$ to 3.53 feet a second, a very different matter.

To pass the required discharge through the vents a head of 1.72 feet is required. Since—

$$Q = 5 \times 30 \times 5.39 \times 5 \sqrt{1.72} = 5,164 \text{ cubic feet second.}$$

This makes water level above the sluice $(1.89 + 1.72) = +3.61$.

The crest of the breast-wall is $+1.50$, so that at low tide the discharge is submerged; with a head of 1.33 feet we shall find that the required discharge is passed. Since—

$$Q = \frac{10}{3} \times 300 \text{ feet} \times 1.33 \sqrt{1.33} + (5 \times 300 \times 2.11 \sqrt{1.33}) = 5,170 \text{ cubic feet per second, the breast-wall being 300 feet long.}$$

Finally, the water level above the breast-wall will now become $(3.61 + 1.33) = +4.94$ (Fig. V). In other words, the effect of building a cushion

wall below the vents is to choke the weir and raise the tail water level of the channel from + 4'50 to + 4'94 or 5 inches. The tail water level under the original calculations was + 3'00, so that this has been raised by practically 2 feet by raising the floor of the sluice; we shall consequently have less fall in the approach channels, which must be made wider than before.

Before I tell you what sizes were chosen, I wish to say a few more words about the sluice design.

Protection against Storm Waves.—The highest tide level at Diamond Harbour is + 15'25, and under ordinary conditions the embankment over the sluice could have been placed 3 feet higher at + 18'25; but the river is subject to storm waves: these waves are generated during severe cyclones. Briefly speaking they are formed as follows: out at sea where the storm rages, the barometer is lowest at the centre of the storm, getting higher and higher the further one is away from the centre; the difference in atmospheric pressure causes an upheaval of the ocean surface, which may amount to about 2 feet at the centre of the storm. In addition to this the wind blows in from all quarters to the centre, causing a further heaping up of the water into the shape of an inverted bowl; as the storm centre approaches the land it meets with the shallows near the coast; the advance of the wave is impeded and further heaping up occurs; as the storm crosses the coast and passes inland the wave rushes up and fills any rivers and creeks immediately in its course, and so forms a wave in the river in addition to that created by the tide. If the time of high water and the advent of the wave coincide, a maximum wave will be created in the river, which may do extraordinary damage. If they do not coincide the effect will be less.

In the northern hemisphere the storm wave always occurs on the east of the centre of the storm, and never on the west. If therefore a cyclone travels to the mouth of the Hooghly and the centre passes up the western bank, a wave will occur in the river. If it passes up the eastern bank no wave will occur.

The largest storm wave recorded in the Hooghly was that of 1864, which rose to 23 feet above mean sea level, or 7 feet 9 inches above the maximum tide level; as the top of the embankment was 19'00 a large volume of water spilled over the top, the embankment was breached in many places, and great loss of life and property occurred. Provision had therefore to be made at the sluice to prevent overtopping during such waves, and the crest of the embankment was made + 24'00.

Protection from blowing through.—Another point which has to be taken into account is the length of the floors of the sluice; if made too short, there is always the liability of the water finding its way underneath and blowing up the sluice especially where the foundations are of sand; supposing the inner channel was empty and a storm wave occurred, rising to + 23'00; as we have seen the bed of the inner channel is at - 6'00, so that the head against the sluice would be 29 feet, the water with such a head will try to creep along the underside of the foundations, and when it starts oozing out at the upstream side it will gradually convey sand with it; a small channel will thus be formed which with such a head will very rapidly get larger and larger; the larger it gets the faster will it increase, until the sluice becomes so hollow underneath that it will crack and gradually break up and burst.

I will show you how to make the necessary calculations for the sluice as eventually built, a section of which is before you (Fig. V). The idea is to "kill" the head gradually by giving sufficient weight to the structure, which will compress the sand underneath and by so doing increase the friction; the forces tending to damage the sluice are the tendency for the water to creep through the sand under the floor and the upward pressure tending to lift the floor, or the hydrostatic pressure.

We have to take the worst case; the maximum head to be killed is 29 feet.

The formula used is: $H = \frac{AP}{C}$ where H is the head to be killed.

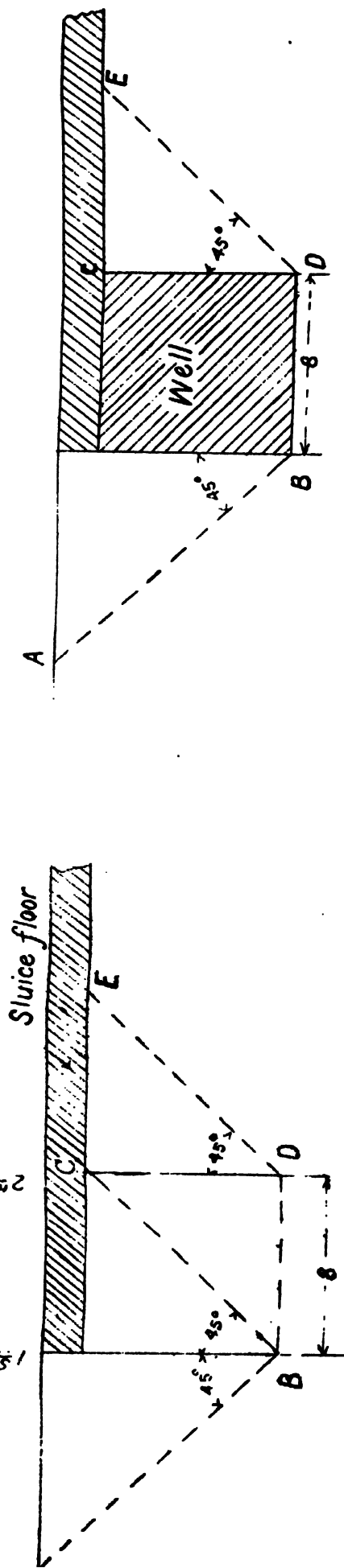
A = the cross sectional area of the material used to compress the sand, *i.e.*, the brickwork, concrete or any other material used.

P = the specific gravity of the material, water being taken as 1'00.

C = a co-efficient depending on the coarseness of the sand.

FIG. XII (b)

1st Line sheet piling



In coarse sands such as found in the Sone and upper reaches of the Damooda, Cossye, etc., in Bengal the co-efficient is found by experience to be 75; for the micacious sands of the Jamna, Ganges and Indus it is 100. For the Nile, which is worse than the latter, it is 125; for the Diamond Harbour sluice it was taken as 100, as the sand, though very fine and easily moved by water, was very compact.

Effect of Sheet Piling and Wells.—Now if there were no drop walls the weight available for killing the head would be that contained in the floors and superstructure of the sluice; the lower floors would of course be submerged and the effective weight will be reduced. The specific gravity of brick masonry and concrete in air is 1·8, and when submerged $(1·8 - 1·00) = .8$; the specific gravity of sand in air is 1·5 and submerged $= (1·5 - 1·00) = 0·5$. The effect of the drop walls is to force the water downwards and under them, and an allowance has to be made for the effect of this in killing the head; if a line of sheet piling is driven down the effect will be equivalent to increasing the weight of the floor, by the weight of the sand contained in a triangle with one apex at the bottom of the piling, and with two sides slanting up at 45° to the floor or channel bed (Fig. XIIa).

The weight of sand contained between the two dotted lines A B and B E is that taken in the calculation.

If we also provide a second line of piling, say, 8 feet back from the first, the weight to be taken will be that enclosed between the outside dotted lines, A, B, C, D. If now in place of the two lines of piling a well is sunk 8 feet wide, the effect will be the same (Fig. XIIb). The extra weight of the masonry in the well cannot be taken into account, as the well itself is partially supported by skin friction and its full weight does not therefore come into play; it must be considered as so much submerged sand.

Calculation for preventing blowing up.—Now let us apply these principles to the sluice. The water will try to commence creeping under the sluice from the downstream end of the floor, so we must commence our calculations from that end; the head to be killed is 29 feet; the formula is $H = \frac{AP}{C}$; as the water will lie over the whole of the downstream floors, there will be no tendency for the sluice to blow up anywhere on these floors; a critical point is inside the vents which are empty at A (Fig. V), so we will first make our calculations for this point. First we have to calculate AP.—

Lowest floor masonry submerged	...	$38\frac{1}{2} \times 3 \times .8 =$	92·4
Next floor masonry	...	$58\frac{1}{2} \times 3\frac{1}{2} \times .8 =$	163·8
Lower downstream drop wall, lateral influence of sand submerged	...	$\frac{1}{2} \times 13^2 \times .5 =$	42·2
Well considered as sand submerged	...	$10 \times 8 \times .5 =$	40·0
Lateral influence of sand upstream side of well, submerged	...	$\frac{1}{2} \times 10^2 \times .5 =$	25·0

Second well.

Lateral influence of sand submerged downstream	...	$\frac{1}{2} \times 8\frac{1}{2}^2 \times .5 =$	18·1
Well considered as sand submerged, say	...	$9 \times 8 \times .5 =$	36·0
Lateral influence of sand submerged upstream	...	$\frac{1}{2} \times 10^2 \times .5 =$	25·0
Total	...		<u>442·5</u>

The effect of the two wells under the vents will be the same as two lines of sheet piling 36 feet apart, but before the vents can blow up the water will have to pass under the first well on the downstream side; so we must take the effect of this one into account; the value of AP for this well will be:—

Lateral influence both sides (taken as submerged)	...	$2 \times \frac{1}{2} \times 7^2 \times .5 =$	24·5
Well taken as submerged sand	...	$12 \times 7 \times .5 =$	42·0
Total	...		<u>66·5</u>

The total value of AP then becomes $442.5 + 66.5 = 509.0$; and the head killed becomes $H = \frac{509}{100} = 5.09$ feet,

The balance of the head acting upwards at the bottom of the floor of the vents is then $(29.00 - 5.09) = 23.91$ feet, and this is the force tending to blow up the floor. The length of the vents is 28 feet, and the weight of the body from floor level to the crest of the embankment is 630 cwt.; add to this the weight of the floor $28 \times 4 \times 1$ cwt. = 112 cwt. the total weight of the structure acting downwards is 742 cwt. As I have taken the weight of masonry and earth to be 1 cwt. per c. ft., the superficial area is also 742 s. ft., and per foot run is $\frac{742}{28} = 26.55$ s. ft.

This is unsubmerged and the value of $P = 1.8$, and $AP = 26.55 \times 1.8 = 47.7$; that is to say, the weight of the superstructure above foundation level is sufficient to counterbalance an upward water pressure of 47.7 feet, whereas the actual pressure has been found to be 23.9 feet of head at this point; in order that the full weight of the superstructure shall be effective, an invert is generally built in the vents; otherwise there would be a liability for the water to burst up at the centre of the vents.

We will now consider the point at the upstream end of the vents at B. The effect of the two wells under the vents will be, as I said, the same as that of two lines of sheet piling 36 feet apart; AP for these wells is then:—

Lateral influence of sand submerged	$2 \times \frac{1}{2} \times 7^2 \times .5 =$	24.5
Wells and sand between them submerged	$36 \times 7 \times .5 =$	126.0
	Total	= 150.5
And AP of the masonry superstructure		
is as found before = 742×1.8	...	.. = 1335.6
	Total	1486.6

whence $H = \frac{1486.6}{100} = 14.86$ feet of further head killed.

The balance of the head then becomes $(23.91 - 14.86) = 9.05$ feet.

To counterbalance this there is the thickness of the upper floor which is 4 feet, equivalent to $4 \times 1.8 = 7.2$ feet head.

The downward pressure is 7.20 feet and the upward acting under the floor is 9.05 feet, and they are therefore not counterbalanced and the floor would blow up at this point; but I have not taken into account the weight of the water acting on the downstream floor, which also helps to compress the sand below the floor. Taking this into account, the result will be—

$$AP = (38\frac{1}{2} \times 29) + (58\frac{1}{2} \times 27) \times 1 = 2,696$$

$$\text{and } H = \frac{2696}{100} = 26.96 \text{ feet.}$$

The total head to be destroyed is 29 feet and, after taking into account the weight of water on the floors *plus* the weight of submerged masonry, the upward pressure at the downstream end of the vents at point A becomes $\{29.00 - (26.96 + 5.09)\} = -3.05$ feet; in other words, the whole of the head has been killed.

Had there been no downstream floors at all, the point of application of the head would have been at the lower end of the vents; the vents would have killed only 14.86 feet of head, and we should have had an upward pressure of $(29.00 - 14.86) = 14.14$ feet, to counteract which there is only the thickness of the floor which will balance only $4 \times 1.8 = 7.2$ feet of head, leaving 6.94 feet unbalanced and the floor would blow up at this place.

You will therefore see that the effect of having long floors is to ensure the safety of the sluice. This sluice is particularly strong with regard to blowing up, but the protection, as I have already said, was given more to prevent pot-holing below, on account of which a double line of wells was sunk, the upper line forming a second line of defence.

Protection against overturning.—Another point to be considered is the length of the main body of the sluice; this has to be made sufficient to prevent it being overturned by the water pressure; in other words, the weight of the superstructure above the floor has to be enough to cause the

resultant pressure to pass within the middle third of the base ; at the same time the length of the vents must be enough to carry the embankment above, the crest of which must be wide enough for a road.

Suppose the inner channel is empty and at the same time a maximum storm wave occurs, rising to 23 feet above mean sea level, the upper floor of the sluice is at - 3.50 and the total head against it will be $26\frac{1}{2}$ feet, the water pressure will act at a point one third the way up from the bottom $= \frac{26\frac{1}{2}}{3} = 8$ feet 10 inches, and the water pressure per running foot is—

$$\frac{Wh^2}{2} = \frac{62\frac{1}{2} \times (26\frac{1}{2})^2}{112 \times 2} = 196 \text{ cwt.}$$

The weight of the body of the sluice per foot run is 630 cwts., taking the weight of earth and masonry both at 1 cwt. per c. ft. From the above we find that the resultant pressure will pass 2.75 feet from the centre of the base, which is 28 feet wide, or 1 foot 11 inches inside the edge of the middle third, so that the structure will be safe under the worst conditions (Fig. V) ; as a matter of fact, the body could have been made a few feet shorter, except for the reason that the crest of the embankment had to be made 9 feet wide to give sufficient room for a pathway.

Draw and self-acting shutters.—The only other point I need touch on in connection with the sluice design is the shutters ; all tidal sluices are now designed with two sets of shutters, one on the upstream side called the draw shutters, and the other called the swing or self-acting shutters, on the downstream side.

The draw shutters run in suitable grooves lined with channel iron or small joists ; they are worked from the top of the sluice by means of a capstan and screw spear ; the shutters themselves are made of 3-inch teak-wood planks covered with copper or zinc sheets to prevent the toredos, or boring insect damaging them. The spear is attached to the top of the shutter by a bolt, and the upper end passes through the capstan head and is screwed ; on revolving the capstan one way the shutter is raised and the vent is opened and water passes out to the river ; a reversal of the capstan lowers the shutter and stops the discharge ; it has been found that with a head of several feet these shutters can be opened by one man only, if supplied with conical brass frictional rollers.

If the sluice was only supplied with these draw shutters, it would have to be closed every time the tide rose above the inner channel level or twice a day. In order to make it automatic a second set of flap shutters is provided at the downstream end of the vents ; these shutters are constructed in the same way as the draw shutters and they are suspended by a horizontal bar, so as to swing in a vertical plane ; generally two sets of horizontal bars connected with links are used, as much less strain falls on the hinges ; now, when the draw shutters are up, the inner water will discharge to the river as long as the tide is below the inner level, pushing open the flap shutters ; as soon as the tide rises above this level it will attempt to pass through the sluice, but the flap shutters will be pushed back against the mouths of the vents and will prevent it. The sluice will therefore act automatically and the draw shutters can be left up and need no attention. In order that the flap shutters shall close the vents fully, and to give them sufficient clearance below when closed, the floor below the vents is built 6 inches lower than that inside the vents ; the vents themselves were made 5 feet wide and 8 feet high and the shutters about 9 inches longer each way, that is to say, 5 feet 9 inches \times 8 feet 9 inches.

LECTURE No. VI.

Design of Channels.—I must now turn to the subject of the design of the channels. As I have said, the result of raising the sluice floor was to raise the tail water level from + 3'00 to + 4'94; we have therefore 1'94 less fall in the channels, and they must be made of a larger section. It was found before the revised calculations were made that with a flood level of 10'50 in the swamps the whole country was under water and therefore no drainage channels were required in the swamps themselves for disposing of the top of the flood which found its way across country.

There was a large swamp on the Usti-Nainan outfall, only 3 miles from Usti, and it was considered that it was unnecessary to grade the channels beyond this point; actually grading was started at $3\frac{1}{2}$ miles; a fall of 0'10 per 1,000 feet = 0'528 feet. per mile was allowed to Usti, the resulting water level being $(10'50 - 3\frac{1}{2} \times '528) = 8'652$. The diversion channel at Diamond Harbour was increased from $\frac{5}{8}$ th mile in length to a little over 1 mile, to make room for the cross dam at the mouth of the creek, and the longitudinal fall allowed was 0'15 per 1,000 in place of 0'20 per 1,000 previously allowed; this made water level at the head + 5'73.

Between this point and Usti the balance of the fall available was then $(8'65 - 5'73) = 2'92$ feet for about $8\frac{1}{2}$ miles of the creek; below Bindal the creek was wide and deep, and needed no excavation, and a longitudinal slope of 0'05 per 1,000 was allowed for this length of 5 miles, making water level there + 7'05. The balance of fall between Bindal and Usti for $3\frac{1}{2}$ miles was therefore 1'60 feet, which gave a longitudinal slope of 0'46 feet per mile, or 0'09 per 1,000 (Fig. XIII).

It will be unnecessary for me to enter into the calculations for the sizes of all the channels required, as I have already explained to you how they are made. I will just give you those for the diversion channel.

The depth chosen was 10 feet and the bed-width 150 feet in place of 130 feet originally. We find from Jackson's tables that with a longitudinal slope of 0'15 per 1,000 the following discharges are given—

Channel of 140 feet bed-width, discharge = 4,837 c. ft. per second.
 Ditto 160 feet ditto = 5,530 ditto.

Mean 150 feet ditto = $\frac{10,367}{2} = 5,184$ c. ft. per second

which is very close, the discharge required being 5,115 c. ft. second.

Width of land to be acquired.—Now with regard to the width of land required for the channel and spoil banks, we have to obtain this from the cross sectional area of the channel. In the case of the diversion channel the average ground level inside the sluice was + 10'50; the bed level was - 5'00 at the sluice, *i. e.* (+ 5'00 - 10'00), and at the head $(5'73 - 10'00) = - 4'27$; the average of these two is - 4'70; the average depth of cutting will then be $(10'50 + 4'70) = 15'20$ feet.

From the sketch section (Fig. XIV) the area of the earthwork becomes—

$$(150 + 2 \times 15'2) \times 15'2 = 2,742 \text{ s. ft.},$$

and this has to be equally divided on both banks; that is, $\frac{2,742}{2} = 1,371$ s. ft. will be the cross sectional area of each spoil bank. It will not be advisable to heap up the earth too high so as to overweight the banks of the channel, which may cause slips to take place. A suitable height for the spoil will be 12 feet; taking into account the trapezoidal section we shall find that the width of the base of the spoil bank will be 132 feet, and the top width 96 feet, since $\frac{1,371 + 96 \times 12}{2} \times 12 \text{ feet} = 1,368$ s. ft., which is very close. Between the toe of the spoil bank and the top of the channel a berm will be required; this is generally made 20 feet wide; and again at the outer toe of the spoil another berm of 10 feet is wanted to prevent the new earth being washed outside the boundary during the rains.

Main outfall channel

Fig. XIII

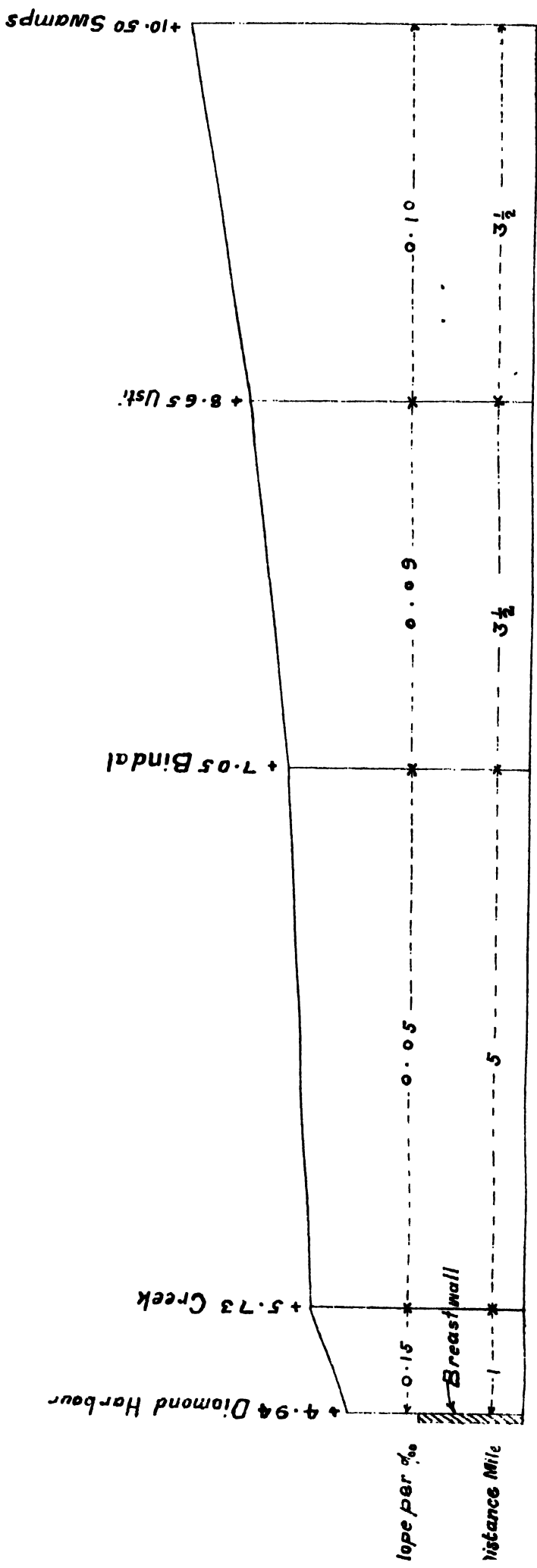


Fig. XIV

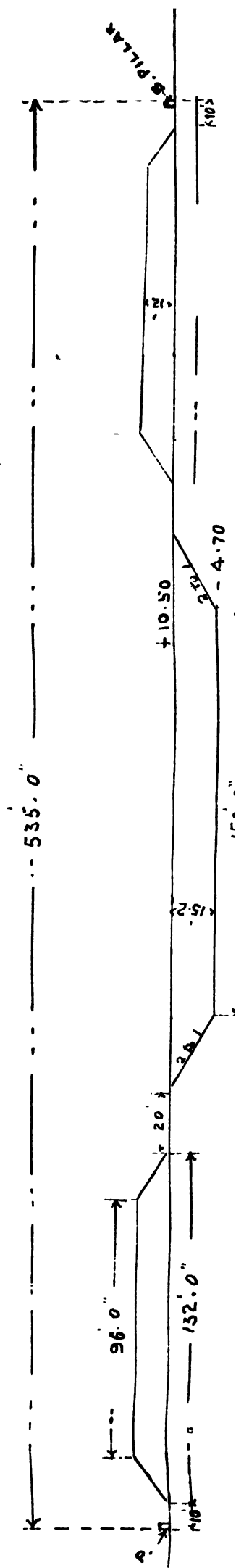
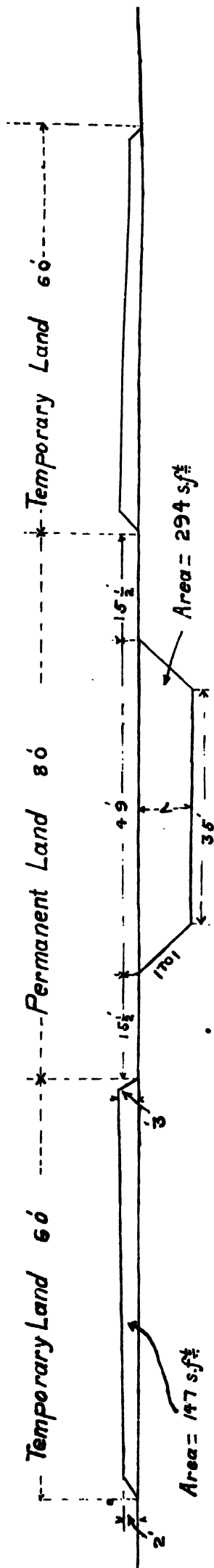
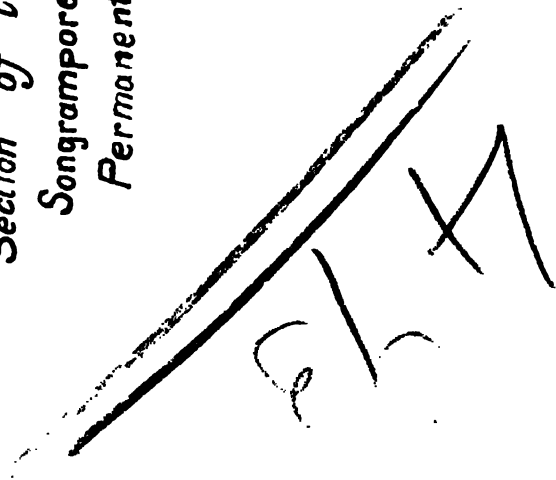


FIG. XV

Section of the Upper end of the
Songrampore Channel Showing
Permanent & Temporary Land



The total width of land then becomes—

Channel bed ...	...	...	1×150	=	150
„ slopes ...	...	...	$2 \times 2 \times 15 \cdot 2$	=	608
Inner berms ...	...	...	2×20	=	40
Spoil banks ...	...	...	2×132	=	264
Outer berms ...	...	...	2×10	=	20
Total ...					5348 feet,

which may be called 535 feet.

We shall then require an average width of land of 535 feet. If the ground levels vary, separate calculations have to be made at each appreciable change in depth of cutting; to save time, the earthwork and land estimates are prepared together as the latter depends on the former.

Other items to be estimated.—The other items to be included in the channel estimate are dressing and turfing the slopes of the spoil banks, masonry boundary pillars for demarcating the land and boundary ridges for the same purpose. In estimating for boundary pillars do not make the mistake of estimating for pillars which cannot be easily seen: they should be 1 foot 8 inches square, 12 inches below ground and $1\frac{1}{2}$ feet above ground. They are generally built every 500 feet, except on curves, where the distance is 250 feet. Between these pillars a boundary ridge of earth is made exactly on the edge of the land acquired. If it is made 18 inches high to start with, it will settle afterwards and will not hide the pillars; these ridges have another advantage: after the spoil bank has been made some of the new earth will wash down during the rains, the boundary ridge will entrap this, and the space between the bank and the ridge will become raised a foot or so, and the neighbouring cultivators can then have no doubt as to where the boundary is, and there is no excuse for encroachments.

The tops of the spoil banks should be sloped outwards from the channel side so that rain water will flow off towards the fields and not towards the channel, thus preventing rain cuts forming down the channel slopes.

One other point about the excavation of the channels: you must remember that when the earth is heaped up in the spoil bank it will occupy a larger area than before it was dug. In fixing up profiles this must be taken into account, as the earth will settle vertically the widths will be the same. On the Magra Hât Scheme we found that an allowance of 2 inches in a foot had to be made. In the above case the amount of settlement to be allowed for will be $12 \text{ feet} \times 2 \text{ inches} = 2 \text{ feet}$, so that the banks have to be made 14 feet high originally instead of 12 feet.

Temporary lands.—In some places the channels passed through the low swamps, and, in order to save in the cost of land, it was decided that the spoil earth should be spread out in a thin layer over the low ground. The land required was with the consent of the tenants acquired temporarily; that is, Government paid a small rate for the land annually while the works were being executed, and afterwards it was handed back to the tenants. The land so raised with the spoil is now used for growing jute and other crops; the average depth placed on the land was $2\frac{1}{2}$ feet; in order to prevent the spoil from being washed back into the channel the banks were made 3 feet high on the channel side and 2 feet on the field side. The land required for the channel itself and 15 feet berms was acquired outright. In the case of the Sangrampore outfall channel at the upper end this was done among other cases: the bed-width of the channel was 35 feet and the depth of cutting was 7 feet; the side slopes were 1 to 1; the quantity of excavation was therefore $(35 + 7) \times 7 = 294 \text{ s. ft.}$; half of this was placed on either bank $= 147 \text{ s. ft.}$, and the width of temporary land required was $\frac{147}{2\frac{1}{2}} = 59$, say, 60 feet; the width of permanent land was $(35 \text{ feet} + 2 \times 7 \text{ feet} + 2 \times 15) = 79 \text{ feet}$, say, 80 feet (Fig. XV).

Decrease in section of Channels in the Swamps.—In some cases where the channels passed through the lowest swamps they were decreased in size as the swamps themselves formed the channels; this was the case in the Usti-Nainan channel. The bed-width of the first $3\frac{1}{2}$ miles above Usti

was 80 feet as it passed through fairly high ground ; it was then reduced to 45 feet in the swamps ; again, where it passed through high lands between village sites at Chakdah, it was widened to 80 feet, and above this again reduced to 45 feet to Nainan, where it passed through the large Magra Hât main swamp. In the low lands the earth was spread out in a thin layer and the land acquired temporarily.

It must not be forgotten that the drainage water must be given free access to the channels, so that gaps in the spoil banks must be left at convenient places. Where this is done provision for extra land has to be made for depositing the surplus spoil, which would otherwise have been placed on the land occupied by the gap.

Minor channels.—Now with regard to the minor channels round Magra Hât, the calculations for these channels were based more on the fact that navigation had to be provided for throughout the year than that they were to be used for drainage. The lowest ground was found to be about +5'00 and this regulates the level of the water in the cold and hot weathers. With water level at +5'00 and the channels graded for drainage requirements only, the beds would have been too high for navigation ; the channels were therefore designed to suit navigation in the dry weather. A loss of 1 foot was allowed due to evaporation and absorption and other causes making minimum water level at +4'00 ; and it was found that for ordinary "donga" traffic 2 feet depth of water was sufficient, so that the beds of most of the minor channels were fixed at +2'00 ; for large boats coming in from the Hooghly and Peali rivers 5 feet depth of water was allowed, and the through channel from Utterbag to Diamond Harbour *via* the Surjipore and Kaorapukur *khal*s to Nainan and thence to Diamond Harbour by the Usti-Nainan outfall and the creek, was designed with a maximum bed level of 0'00 ; to permit of boats entering, a lock was constructed at Diamond Harbour and a second lock is under construction at Utterbag on the Peali.

Gross Dam.—I think I have now given you the main points to be taken into consideration in designing the channels. I will now return once more to Diamond Harbour, and tell you about the diversion of the drainage water from the creek into the diversion channel, and thus through the sluice into the river.

As you will understand, if the water is to be diverted through the sluice the original outlet must be closed up to exclude the tides, to prevent them from doing any further damage by silting up the channels. In this case the main Diamond Harbour creek had to be closed with a dam below the offtake of the diversion channel. You will remember that I told you before, the length of the diversion channel was altered from $\frac{5}{8}$ th mile to a little over 1 mile ; in other words, the offtake from the creek was moved further upstream (*see* Fig. VI) ; this was done to make room for the dam, which required about 50 lakhs of cubic feet of earth. Both of the creek banks further down were crowded with houses, and there was no room to obtain sufficient earth for the dam ; by altering the position of the offtake this difficulty was overcome ; another point in favour of the site chosen was that the dam would be above the bend in the creek in a reach which ran east and west, and it was therefore protected from direct wave action from the Hooghly ; a site near the railway station was therefore chosen, as earth could then be obtained from the diversion channel and the works of both combined and cheapened. The dam could not of course be made till the sluice had been built, and in the meantime the preliminary work was pushed on.

Scouring of the Creek.—While this was going on the tides had free access to the creek up to the mouth of the Dassanni *khal*, and a short length of the upper end of the diversion channel had to be left unexcavated till the dam was made, to prevent the tides entering it and interfering with the work ; it was also thought that by excavating the upper reaches of the creek partially some drainage might be done, and that possibly some of the silt might be washed out of these channels, and the cost of excavating them decreased ; the bed of the creek near the Dassanni *khal* mouth was very high, but the tide passing up and down the *khal* maintained a small channel ; a dam was therefore made across the creek just above this point, and the channels above partially excavated ; during the rains the dam was cut and the

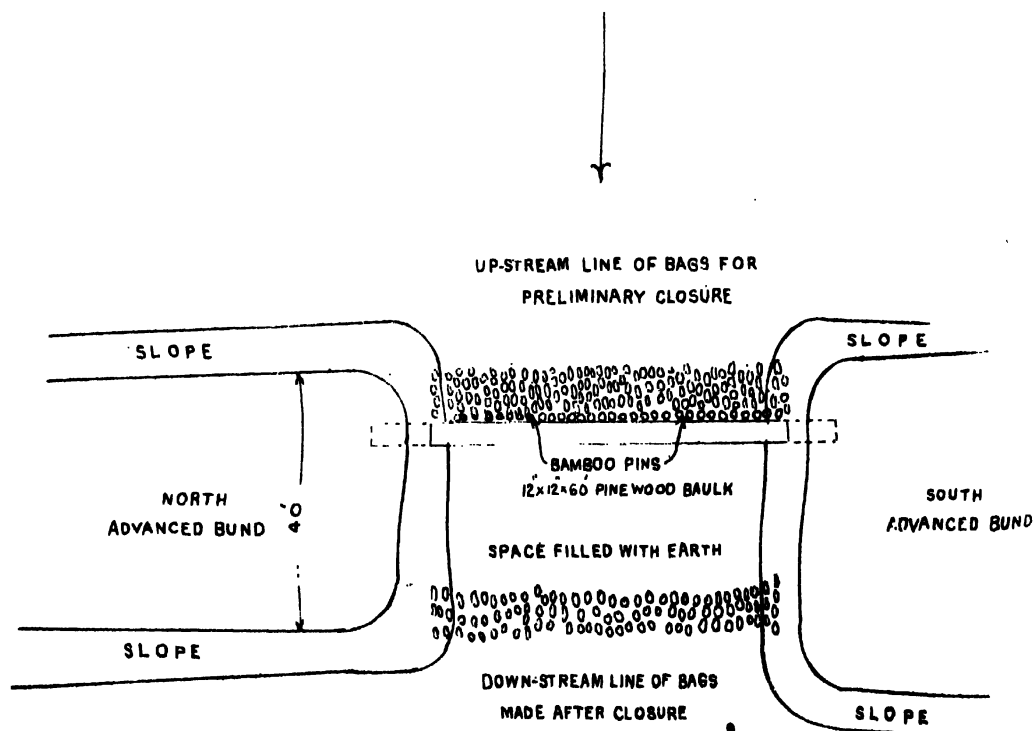
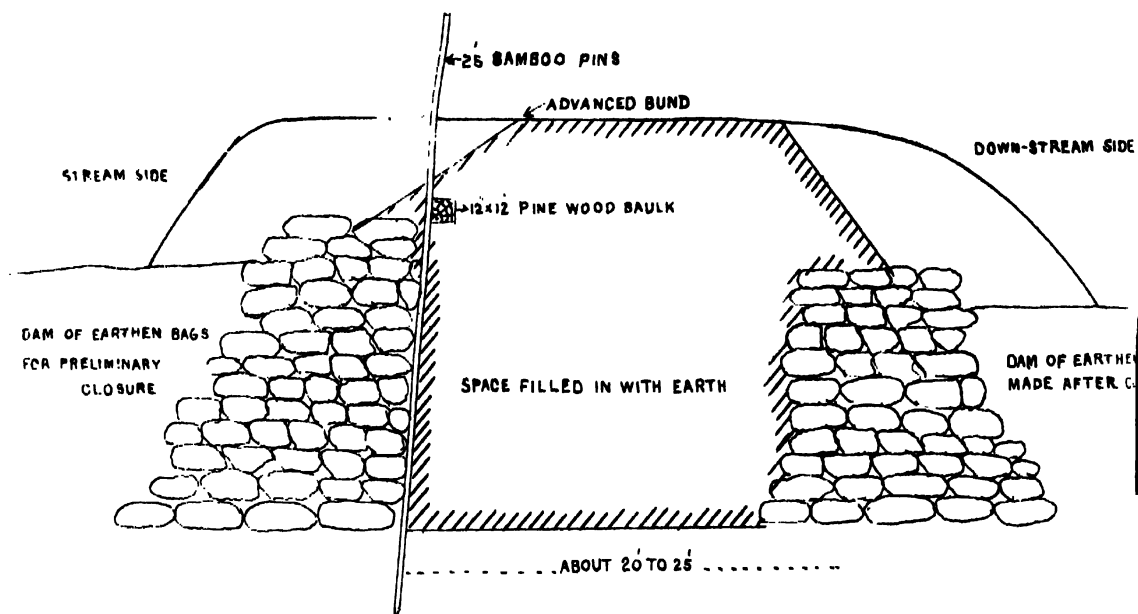
MAGRANAT DRAINAGE SCHEME

Fig XV

DIAMOND HARBOUR CROSS-DAM

SKETCHES SHEWING THE METHOD OF FINALLY CLOSING THE DAM

ON THE 15TH FEBRUARY & 1ST MARCH 1909



drainage water allowed to pass down from the swamps ; the effect was extraordinary ; as the tide flowed and ebbed it stirred up the new silt and during ebb carried it out into the Hooghly ; by the end of the drainage season the Nazra *khal* had scoured out to a section which was slightly larger than that required, and the creek below Usti had widened out and deepened so much that it has been found unnecessary to do any excavation at all, except to straighten some of the worst bends. On the Nazra *khal* alone, which is 2 miles 1,000 feet long, a saving of Rs. 25,000 was made, and in the creek nearly 2 lakhs of rupees were saved.

This case is an important one to remember ; in cases where an old silted channel exists, it may be found much cheaper to follow it than to make a new cut across the fields ; if the silt is new it will wash out easily, once it is started off by making a small cut down the centre of the channel.

Method adopted in closing the Creek with a Cross Dam.—The dam over the creek at Diamond Harbour was made of earth ; the closing work was commenced in November 1908 from both banks simultaneously ; prior to this a large quantity of earth had been collected on each bank close to where the dam was to be made, and this was left untouched till the final closing had to be done ; all the earth from the diversion channel close by was heaped up on the southern bank to decrease the lead ; and on the south bank of the creek a large quantity was dug from the land on the west of the dam and heaped up on the centre line ; to obtain earth for the preliminary dams tram lines were laid down and the earth brought from the longest leads first ; this was tipped on to the banks of the creek which were covered with mud ; as the earth was thrown it slipped down into the bed displacing the silt at the bottom of the river ; this heaping up of earth was continued till the end of January 1909, and by this time the clay had extended from either bank into the middle, where it met, forming a hard apron which could be seen at low tide, which formed a hard foundation on which to build up the dam ; to prevent excessive expansion of the clay apron sideways a large quantity of bamboo piling was used ; this was driven with mallets at low tide ; it was found that the most effective piling was what is termed cross-piling ; it consisted of bamboos 25 to 30 feet long driven at an angle of 45° both ways and tied together with horizontal bamboos and string, as in the sketch (Fig. XVIa) ; several such lines had to be made on either side of the dam ; as the first one was pushed out by the moving earth, a second was made closer, and so on ; these lines of piling are shown on the plan (Fig. XVI).

By the end of January 1909 the width of the creek had been decreased from 450 feet to 250 feet and the bed had been raised from - 19'00 to - 10'00 on the average. The first three attempts to close were failures, as the dams which were made across the gap were breached, and it was not till the fourth attempt on the night of the 1st March that success was attained.

•As the channel was gradually narrowed by advancing the two embankments the tides continued to flow through the gap and the velocity increased ; in order to protect the noses of the embankments a good deal of brushwood was used ; this was placed along the noses and held in position by bags of earth, and it formed a most effective protection. As the tides got lower and lower the noses were pushed out further, so that by the time the tides had fallen to their lowest the gap was only 55 feet wide ; on the night of the 1st March the closure was made ; the dam was pushed forward still further during the ebb tide, and the gap narrowed down to 44 feet ; a large pinewood baulk 60 feet long and 12 inches square was then hauled across and the ends embedded in the noses of the advanced embankments. (Fig. XVII) ; on the upstream side of this baulk bamboo piles were driven about 6 inches apart, thus forming a needle weir ; bags of earth were then thrown in as fast as possible on the upstream side of the piles which prevented them being carried away by the swift current ; a dam was thus formed with earthen bags right across the gap and the current stopped. In the meantime the noses were pushed on, and before the tide turned an earthen embankment had been made right across in the still water below the bags of earth ; this was then gradually raised as the tide rose ; this work was done during the lowest neap tides, and as the tides rose daily higher and higher the dam had to be raised to prevent overtopping. I have not given you the full details of the

method of doing this work, but have only outlined the main points ; all I wish to do is to put before you the chief points to be kept in view when constructing dams across tidal streams. The full details are given in my report on this work dated 11th May 1909 ; in some cases where the *khal* to be closed is a small one, an old country boat is purchased and at the time of closure is floated into the gap and sunk there ; it is generally filled as full as possible first with bags of earth ; as soon as the boat is sunk the current is to a great extent stopped and an earthen dam is carried over it.

After closure when raising the height of the dam, *care must be taken that no earth is thrown during ebb tide* ; work should be completely stopped on the dam itself ; as the tide recedes the pressure is relieved and the earth on the downstream face will slip down ; any further earth added at this time will increase the slipping ; work should always be carried on during the flow tide when no slipping will take place ; but before so doing, all cracks must be cut out, refilled with earth and well rammed. As the dam is increased in height, the base must be widened ; this widening must all be done on the *downstream or tide side*, and *no earth should be thrown on the upstream side* as this may cause a general slipping of the whole dam. The first thing to do as soon as the tide turns is to fill up the hollow caused by the slip, layer by layer ; each layer should be about 2 feet thick and should be started from the ends nearest the banks of the river, and gradually advanced to meet in the middle ; the coolies then have to pass over the new layer as it is formed and will consolidate it ; if there is time after the hollow has been filled, widening may be done on the downstream side by throwing earth on to the slope, but care must be taken to watch the rate of rise of the tide to see that it does not overtake and overtop the embankment ; it is generally better to do the raising first and the widening afterwards.

Work will have to be continued in strengthening and raising the dam till the next highest spring tide ; after this it is advisable to leave the dam alone during the ensuing neaps to allow it to settle and dry ; after this it can be made up to full section.

As work has to be carried on every flow tide it is necessary to have plenty of lamps to give a good light at night, so that the smallest crack in the dam can be detected at once and cut out and rammed ; specially experienced men must be employed for this. If these cracks, which are due to settlement, are not found at once, the dam may be breached ; it only requires a few minutes for this to occur in some cases.

The crest of the embankment was eventually made up to +27'00 or 4 feet above the level of the maximum storm wave, and the crest width was made 25 feet to carry a metalled road ; the slopes were also turfed.

Increase in the "Run off."—I mentioned before in a previous lecture that the "run off" was taken as 0'6 inch in 24 hours in place of 0'75 inch owing to a mistake in the calculations, but that from actual practise it is 0'96 inch with water level in the swamps at +9'00. The reason for this is that the Peali sluice discharges about twice the quantity of water necessary to drain its own basin of 25 square miles, and the capacity of the Diamond Harbour creek is very great ; in calculating the sizes of the channels below Usti we assumed that the discharge would cease when the tide was above +7'00 ; as a matter of fact this is not the case ; the creek is so large below Bindal that the level of the water rises very slowly ; practically no backing up occurs at Usti and therefore there is full discharge throughout the 24 hours at this place ; we found that the sluice remained closed for $2\frac{1}{2} \times 12 = 5$ hours per tide, and it is therefore clear that the creek is capable of storing all the water which flows down into it during this period from the swamps ; when the sluice opens again on the falling tide all the water thus collected passes out into the river, and the creek is emptied sufficiently to collect the water during the next closure ; what happens of course is that the sluice discharges more water during the time it is open than shown by the calculations.

I have now given you the main details of the works executed for the main Diamond Harbour basin ; the only works I have not mentioned are the bridges and ferries and quarters for the staff ; the type of bridge used mostly was of the screw pile pattern as the foundations were generally of fine sand ;

these bridges were built where the main roads crossed the channels; in other places, where traffic was small, ferry boats were supplied. I do not intend going into the details of these works, but will now turn to the other two portions of the scheme, the Surjipore and Habka.

Surjipore section.—The old Surjipore sluice was situated at Surjipore on the *khal* of the same name and about 6 miles from its mouth, and was built about 45 years ago, at a time when the country between it and the Peali river was unreclaimed and was covered with jungle; since then the whole of the land has been cultivated, the result being that tidal spill has been cut off and the sluice left inland with no spill to keep open the *khal*. The *khal* of course began to silt up, and the only way to prevent it closing up altogether was to silt-clear it periodically; when the Magra Hât Scheme was proposed it was ascertained that this basin formed part and parcel of the Diamond Harbour basin, and that the two could not very well be separated; the sluice lay across the *khal*, thus forming a dead end, and the tides used to carry up silt from the Peali river and deposit it below the sluice; during ebb tide there was practically no current to wash it back into the river and there it remained choking up the *khal*.

It was therefore decided to build a new sluice at the mouth of the Surjipore *khal* and to close the *khal* with a dam at the mouth.

Sluice Calculations.—The area drained by the new sluice is 25 square miles, and, allowing a "run off" of $\frac{3}{4}$ inch in 24 hours and for full tidal action, a discharge of $\frac{3}{4}$ of $25 \times \frac{3}{4} \times 26.9 = 757$ c. ft. per second is required; with a depth of water over the breast-wall of 3 feet, the length of breast-wall required is 44 feet and three vents are sufficient; but in order to assist the main sluice at Diamond Harbour an extra two vents were supplied and the length of the breast-wall was increased to 60 feet. The lower reaches of the *khal* were in fair order, as the dam at the mouth was made soon after the drainage season, and the channel had scoured out to a good section, and only about $1\frac{1}{2}$ miles at the head had to be excavated; this channel acts to a great extent in the same way as the Diamond Harbour creek and a large quantity of water ponds up in it when the sluice is closed; from actual observation it has been found that this sluice discharges about 1,600 c. ft. per second, with an ordinary flood at low tide, or about $1\frac{1}{2}$ inches per day from its basin; or, putting it another way, it drains at the rate of $\frac{3}{4}$ inch in 24 hours from 50 square miles; that is, it is twice as powerful as originally intended.

The works undertaken for this part of the scheme were the construction of the Peali sluice, closing the Surjipore *khal* at its mouth, partially dismantling the old sluice at Surjipore and converting it into a bridge to give more waterway for drainage and navigation, and the construction of a new embankment along the right bank of the Peali river, 8 miles in length, to protect the land which had been reclaimed and was already protected by small zamindari embankments which prevented any spill taking place.

Habka Section.—I will now turn to the third section of the scheme—that of the Habka basin: its area is 50 square miles, and the discharge of the sluice will be twice that for Peali sluice or $2 \times 757 = 1,514$ c.ft. second; 4 feet of water was allowed over the breast-wall and the length required was 56.7 feet, which was called 60 feet; the area of the water passing over is $60 \times 4 = 240$ square feet, and the same area was given in the vents; six were allowed of 8 feet \times 5 feet = 240 square feet; the only channel existing through which any drainage could be done was the Kharampara *khal*, and this had almost silted up; all the other *khals* were level with the fields and many of them had been turned into paddy-fields; the Kharampara *khal* entered the river about a mile above Dhosa, whereas the site chosen for the sluice was close to Dhosa; at this place an old *khal* existed which it was decided to utilize for the outfall channel; before the sluice was made, cuts used to be made in the embankment at this place for drainage; on the last occasion the cut widened out to such an extent that it got out of control, and the *khal* deepened and widened out so much that it had to be eventually closed a mile inland, and marginal embankments were made along its banks to prevent the tide spilling over the fields; above the place where the dam was made the old *khal* existed for another mile, and was used for the out-fall; below the dam the *khal* had filled up with silt which had to be

excavated. A cross dam was made across the Kharampara *khal* at its mouth, and in order to divert the water drained by it a new cut, a mile long, was made from above the dam to the sluice channel above the sluice.

The main channel was extended to the south to join up with the Borar *khal*; the section was decreased gradually from 60 feet bed-width at the sluice to 5 feet at the upper end, according to the area drained; from Udkhali to Barasat one of the minor channels was excavated with a bed-width of 10 feet and bed-level at + 2'00 to form a connecting channel between this section of the scheme and Magra Hât for navigation; suitable bridges were constructed, where required, over the channels.

The works were of the ordinary kind, but there is one point which I should like to draw attention to in connection with the sluice design; the largest swamp lies close to the sluice about half a mile away, and almost all the water from the basin drains of its own accord into this swamp across the fields; in fixing the level of the crest of the breast-wall the channel was graded from a point some 5 miles away from the sluice, with the result that when the sluice was brought into operation there was a tremendous rush through it at low tide; no account had been taken of the proximity of the large swamp, so that a much greater depth of water passed over the breast-wall than estimated, and the sluice was very nearly washed out; grading should have been started from the main swamp close by, instead of 5 miles away; the breast-wall had to be dismantled and a higher one built in its place.

I have now given you the principal details with regard to this large drainage scheme, and in doing so I have attempted to bring before you the chief difficulties met with in carrying it out, so that you will be able to foresee them if ever you have to do work of this nature. I would also impress on you the necessity of seeing that all materials used in the works are of the very best obtainable; in the case of bricks this is of the first importance, as the salt in the water will attack any that are not thoroughly burnt and they will rapidly crumble to pieces.

Arapanch and Khari Basins.—I will now briefly outline the proposals put forward for draining two of the other basins inside the embankment. I have already mentioned the Arapanch and Khari cases, where the sluices were built across the drainage *khangs*, forming dead ends as in the case of the Surjigore sluice.

The Arapanch basin drains into Tolly's Nulla through a branch *khal*. The sluice is built across the branch *khal* about $2\frac{1}{2}$ miles from its mouth, heavy deposits of silt occur below it, and in addition to this the deterioration of the Bidyadhari river has extended to the nulla itself. The outfall to the Bidyadhari is therefore in a very bad state, and the basin cannot be properly drained.

To get over these difficulties it has been proposed to cut an entirely new outfall channel direct to the Peali river, and running parallel with the Eastern Bengal State Railway, the channel being sluiced at its mouth. The advantages of this scheme are:—

A shorter "lead" to the main river and therefore a greater longitudinal slope resulting in a cheaper channel, and a much better river into which to discharge the water. In the middle of the basin the ground is very low, being about + 3'00, so that very low levels have to be worked to in designing the sluice. This is an example of a case in which an entirely new outfall had to be looked for, on account of the existing sluice being badly situated at the upper end of a dying *khal*.

Another similar case is that of the Khari sluice. This sluice is built across the *khal* of the same name and is situated 6 miles away from the main river. The *khal* is now of little use as it is fast closing up. New works were therefore proposed, which consist of a new sluice and outfall channel draining into the Moni river, the sluice being placed close to the bank of the river. This river is not in such good order as could be wished, but it is the only one in this locality which is of any size. It will probably suffice for the next 20 to 30 years, but it is already silting up rather fast. The works have recently been commenced.

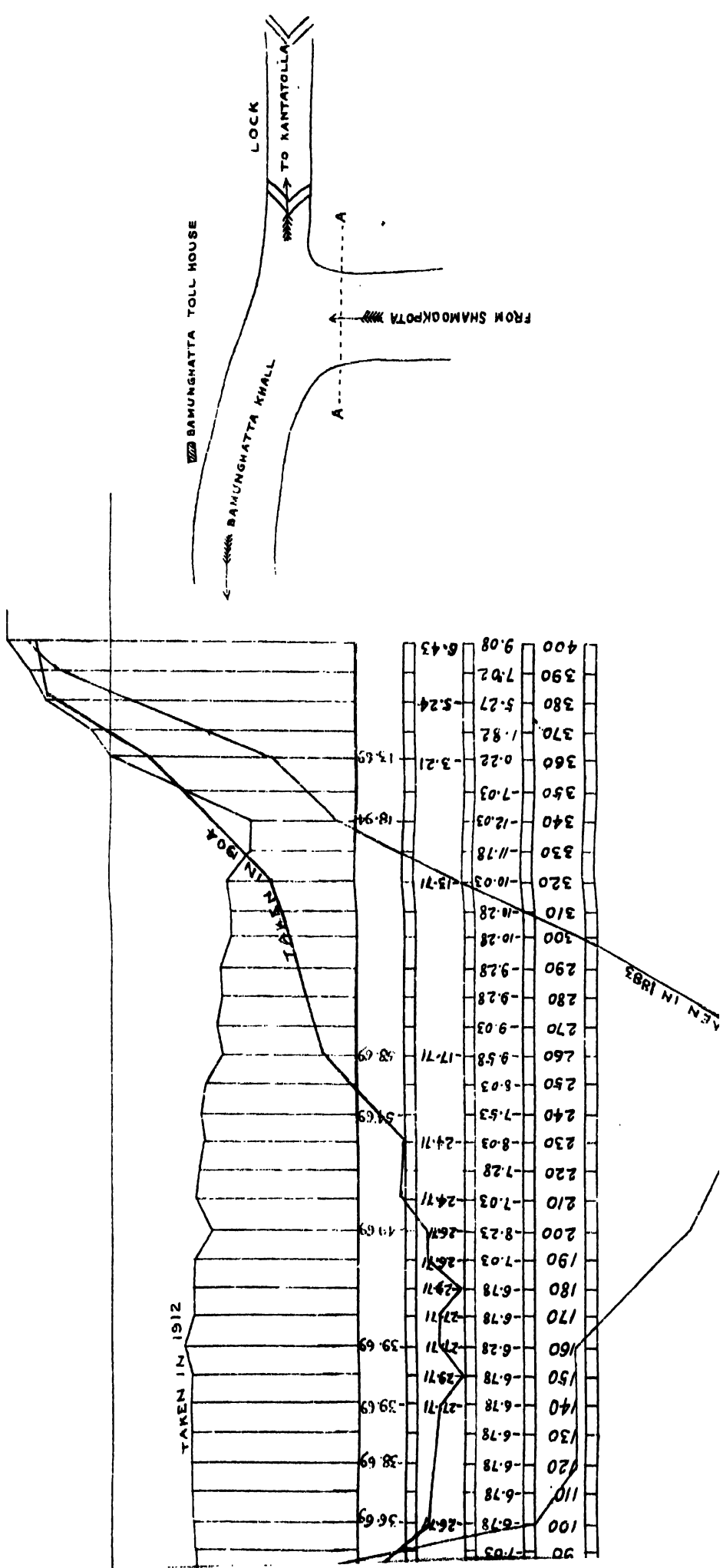
Deterioration of the Bidyadhari River.—I mentioned in a previous lecture the case of the Bidyadhari river. This river used to spill freely into

Fig. XVIII

CROSS SECTION OF THE

BIDIADHARI RIVER

SHOWING RATE OF DETERIORATION



the Salt Lakes to the east of Calcutta. It joins the Mutla at Port Canning. The silt carried up by the flow tide used to be deposited in the lakes themselves, and the tides had free access to the lakes on both sides : as the land has gradually risen, attempts have been made to reclaim portions of the lakes, while the remaining area has been converted into large fishery grounds. The latter did no harm so long as the free spill of the tides was allowed to continue. But at the present day matters have altered entirely. The water from the river is now only occasionally allowed to spill into the fisheries and is also only occasionally drained out. This river has been kept alive entirely by tidal spill, draining very little rain water comparatively speaking. Now that the free spill has been interfered with, the river is rapidly decreasing in section and at the present moment the bed is silting up at the rate of nearly 3 feet a year. I have here a section of this river where it passes through the lakes (Fig. XVIII). You will see that in 1883 it was a deep river, the lowest level of the bed being 58'69 feet below mean sea level ; in 1904 the bed had risen to 29'71 feet below mean sea level. Now it is only 6 feet below the same datum. The average bed-level is now only about 5 feet below mean sea level. Thus in 30 years the bed has risen 53'7 feet, or, say, at the rate of about $1\frac{3}{4}$ feet per annum. Since 1904 the silting has been more rapid. In nine years the lowest level of the bed has risen 23'70 feet, or at the rate of 2'63 feet per annum ; at this rate the river will probably entirely silt up within the next ten years or less. At Port Canning the Bidyadhari, Kultigong and Atarabanka all join to form the Mutla. The Atarabanka is for all practical purposes a dead river. The bed of the Kultigong is high and dry at half ebb tide, and the Bidyadhari will be dead shortly if the present conditions are allowed to prevail. It follows then that the Mutla must follow suit before long. In fact the sections I had taken of this river recently show that deterioration has set in already.

There is only one practical way of prolonging the lives of these rivers, and that is by allowing the spill to take place again freely. They cannot be kept open by dredging as the cost would be enormous.

The bed of the Bidyadhari has now become practically level ; this is a sign of deterioration. A tidal river in good order has either a V or U section round the bends. This type of section is now disappearing on this river, showing that the current is not sufficient to create a scour.

The river also gives a good example of the care which must be taken in fixing the site for a drainage sluice. At Bausra the river is travelling south at the rate of between 200 to 300 feet a year. A large horse-shoe bend has formed at this place which has been extending itself for at least the last 35 years. The position of the river at this place is now about $1\frac{1}{2}$ to 2 miles further south than it was 35 years ago. No one would therefore think for a moment of building a sluice on this bend.

• In conclusion, let me give you a little advice : never, if possible, fall out with the cultivators whose land you are going to drain ; keep in with them, and, as far as possible, do what they want with regard to the alignment of your channels. You will sometimes meet with opposition to a particular alignment. Do not brush this aside without fully going into the matter. If you can, without extra expense, divert your channel a little this way or that. If you eventually choose an alignment which is accepted by all, you will have no further trouble, whereas if you do not, you will probably find that the scheme will be delayed, which means extra expense and perhaps the loss of a year's crops.

As far as possible, allow the local people to do the excavation of the channels ; they are the people who will eventually have to pay for the scheme, and it is only right that they should receive a refund in the way of wages. The money spent should, as far as possible, go back to the people who are interested and have to pay. On the Magra Hât Scheme practically the whole of the channels were excavated by the local people, each village turning out to excavate the channel nearest it, and at one time about 5,000 local men were employed. Another point is that, at the time the scheme is being carried out there will be a certain amount of distress locally, and the wages earned by the villagers will enable them to tide over the time of scarcity until they can again raise good harvests.

